SEASONAL AND DIURNAL PATTERNS OF BEHAVIOUR AND MOVEMENTS OF THE CANADA GOOSE (*BRANTA CANADENSIS*) IN CHRISTCHURCH CITY AND CENTRAL CANTERBURY, NEW ZEALAND

Thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Ecology at the University of Canterbury.

By Henry James Caley

2020

ABSTRACT

The growing conflict between wildlife and humans continues as we expand our reach and movements globally. In New Zealand, the Canada goose (*Branta canadensis*) was introduced last century as a game species but recent increases in their populations present concern for civil and military aviation in the region as there is little information on the movements and behaviour of geese in this region. Utilising GPS tracking technology, I investigated the spatial and temporal patterns of Canada goose movements in central Canterbury. Transect surveys were also used to identify key habitats and quantify behaviours of urban goose populations in Christchurch. Field surveys and tracking of geese were conducted from November 2018 to January 2020. GPS-collars were fitted on 10 Canada geese at three habitats; Lake Ellesmere/Te Waihora (n = 3), Lake Grasmere (n = 3) and central Christchurch city (n = 4). A detailed study comparing the behaviour of geese fitted with GPS collars and control birds (no collars) found no major differences, indicating the collars likely had little effect on the geese. Long distance movements of Canada geese mostly occurred during spring with birds flying >20 km and as far as 115.6 km from point of being tagged. The long-distance flights coincided with a dispersal of geese away from the coast to inland breeding sites. Long distance movements took place again in early summer when geese returned to coastal moulting sites, travelling up to 128.8 km. Home range size varied between individuals, with the range of a Lake Ellesmere/Te Waihora goose spanning 20,540 km^2 during November 2019. In contrast, city birds only averaged ranges of 9.47 km^2 for the whole year, with a single goose peaking at 80 km^2 in August. Data on altitude and velocity of flights showed peaks during September and two distinct increases in diurnal activity from 05:00 to 08:00 am and 16:00 to 20:00 pm. Foraging behaviour was seen most often in 'red zone' paddocks and showed significant increases from spring to summer, and then decreases from autumn to winter. These trends coincide with the moult period and increase in body condition for winter, respectively. A large resident population of Canada geese in the Christchurch area, along with overwintering densities reaching 112.8 geese/ha on urban lakes, poses questions about whether this increase is the result of an influx from rural populations or a consolidation of urban birds in fewer sites. This study presents results that may assist future management of Canada geese and improve the assessment of the risk they pose to civil and military aviation in the Canterbury region.

Keywords: *Branta canadensis*; Canada goose; GPS; wildlife tracking; telemetry; residency; behaviour; New Zealand; movement.

Abbreviations: ASL (above sea level), AGL (above ground level), GPS (Global Positioning Systems), GSM (Global System for Mobile Communications).

Figure 1.0. Goose 3519 “Charlie” tagged at Lake Ellesmere/Te Waihora in January 2019. Charlie performed the longest flights and bred in the centre of the Southern Alps. Charlie still survives to this day and is back on Lake Ellesmere.

Contents

Tables

Figures

Page

ACKNOWLEDGEMENTS

This thesis would not have been achieved without the support and thoughtful considerations of many people. Firstly, I would like to thank Jim Briskie for his mentorship for not only my postgraduate years but for also providing me with much summer work throughout my undergraduate degree. These experiences have ultimately led me in a direction that I am now very grateful for and have prepared me for the next big step in my career.

I would also like to thank Anna Parfitt who has been my number one supporter during these last few years. Anna has put up with many of my struggles but has always provided the positivity and love that has assisted me while completing this thesis. Archie MacFarlane has been a great friend and mentor throughout my time in the Biological Sciences Department. He has provided me with opportunities to work with South Island robins in the Marlborough Sounds and despite some disastrous conditions we kept each other sane. I shall not forget his dedication and the sacrifice of his forearms to catch Canada geese for this investigation. Equally fearless, Jim, Nyil Khwaja, Emma O'Donnell and Collin O'Donnell were also pivotal volunteers who helped to catch Canada geese to fit GPS collars on; thank you for your help. I thank Emma O'Donnell particularly, who with her two kayaks met me at 3 am to drive to Lake Grasmere to kayak across the fog covered lake and help catch geese with nothing but our hands and a net whilst Jim could only watch on and listen to the honking through the fog. I thank the Christchurch City Council Ranger teams, Andrew Crossland and Kenny Rose especially, who helped to coordinate goose catches within the city properties. Without their help this would have been much harder to accomplish.

Funding for this project was provided by the Christchurch International Airport (CIA). I am grateful for the money they provided to support a scholarship to myself, and for the costs of the field research. None of this thesis would have been possible without their generous support. A number of CIA staff helped over the course of the project and I greatly appreciated their support and advice: Norm Mannix, Mike Weir, Tim Morris and Brodie Akacich. I hope my work will help in how you manage geese in the future, and I look forward to carrying on collaborating in the years ahead.

Finally, a special thanks to my parents who have both been a great support to me during my return to university, after having finally found my passions. They have provided me with respite and love whenever I needed a break away from study. My mum Carol sent care packages that were always welcome, and my father Simon was always interested in reading and helping me to check my grammar and structure throughout my thesis.

CHAPTER 1

1.0 GENERAL INTRODUCTION

Ecology and movements of Canada geese in their native North American range

The Canada goose (*Branta canadensis;* Family Anatidae) is one of the most morphologically varied species of geese and is currently separated into 11 subspecies, comprising 7 large-bodied and 4 small-bodied forms (Bellrose 1980; Shields & Wilson 1986; Baker 1998; Shields & Cotter 1998). All are native to North America. Canada goose populations in the early 2000's were estimated to be between 3 and 5 million birds in North America, possibly reaching 8 million birds (Mowbray et al. 2002). There are four main migratory flyways for waterfowl in North America; Pacific, Central, Mississippi and Atlantic (Hill & Frederick 1997) (Figure 1.1), and together these encompass 25 managed populations of Canada geese. Seven of the 11 subspecies of Canada geese reside predominantly within the Pacific flyway with breeding in northwest Canada and Alaska (Bellrose 1980). The remaining three flyways are distinguished by populations rather than subspecies. For all flyways, Canada geese have been rapidly increasing in numbers (Fox & Madsen 2017; U.S. Fish and Wildlife Service 2017), in-part due to agricultural food provisions (del Hoya et al. 1992) that with modern farming practices are reliable sources during winter. Breeding ranges have also shifted towards wintering grounds within all 48 continental states of the USA and all Canadian provinces by 20th century (American Ornithological Union 1998).

Along migratory paths, geese historically followed the spring-flush periods of grasslands, crossing latitudinal gradients towards high latitude breeding grounds (Owen & Black 1990). Fox and Abraham (2017) suggested that the abundance and ranges of European goose populations are expected to increase alongside agricultural improvements into the near future. This is because as humans have increased the yield and nutritional value of crops and grasses, the requirements for regular animal movements could decrease. The limiting factors of

Figure 1.1 From: Anderson & Padding, (2015). Administrative and biological boundaries of flyways for waterfowl species in North America. Maps of administrative and biological flyways. http://www.flyways.us/flyways/info (Accessed 9 October 2019).

winter survival are reduced (Fox & Madsen 2017) thus, providing difficulties for current and future mitigation strategies of geese populations. As populations of geese become increasingly reliant on human food production, major adaptations of these practices in response to climate change could create uncertainty for goose populations and their welfare (Fox and Abraham 2017).

Most populations of Canada geese tend to have breeding- and wintering-site loyalty, returning to the same breeding and wintering areas, and following similar migration pathways. However, Canada geese also display a wide level of plasticity in response to novel challenges (Dorak et al. 2017), a pattern seem in other species such barnacle geese (van der Jeugd and Kwak 2017; Stroud et al. 2017), suggesting that the shifting wintering and breeding ranges to more anthropocentric environments may produce more varied and unpredictable movements. The prospect of future climate change on native breeding sites also raises concerns for fragile tundra ecosystems as some breeding sites already shows degradation in response to rising goose numbers (Abraham et al. 2005; Buij et al. 2017). Plasticity in long-distance migratory species may be an advantage as the chances of mis-matching optimal foraging periods in distant breeding grounds become more likely (Parmesan 2006; Both et al. 2006; Durant et al. 2007).

Ecology and movements of Canada geese in their introduced ranges

Canada geese have been introduced in a number of places around the world. They were first introduced to England during the 1665 reign of King Charles II and included in the regent's waterfowl collection of St James's Park (Allan, Kirby & Feare 1995). Further collections were made within London and three counties in Northern England in the same period (Owen 1983). In the centuries that followed, the population of Canada geese in the U.K. remained below 4000 individuals until the mid-20th century. Impacts of Canada geese on agriculture near London led to the relocation of >700 birds to areas of southern Britain (Ogilvie 1969), implemented by the Wildfowl and Wetlands Trust. Until this translocation, the population of geese had shown considerable natal-site loyalty. Reservoir construction near to agricultural lands and improved wetland conservation provided additional breeding and feeding sites that then led to a rapid population growth of Canada geese (Allan et al. 1995; Figure 1.2). The success of Canada geese in the UK was likely due to both their adaptability and the creation of habitat that indirectly benefitted many waterfowl species across the UK. In Britain, the first census for Canada geese took place in 1953 and was estimated at 2,200-4,000 individuals (Blurton-Jones 1956). By 1967-1669 surveys estimated 10,500 geese and observed new locations of occupation (Ogilvie 1969). Populations continued to increase in the years that followed: 19,400 geese observed in 1976 (Ogilvie 1977), and 63,581 observed in 1991, an increase of 220% since 1976 (Delany 1992). From 1988-1991 the 'New Atlas' bird counts estimated 59,500 adult Canada geese (Gibbons et al. 1993) and by 2000 the population was estimated to be 88,866 Canada geese (Austin et al.

2010). During the 21st century estimates reached 120,000 with 96,000 residing in England alone (Hansard 2005).

The Canada goose was introduced to New Zealand in the early 20th century, primarily to promote a tourism industry based on big-game hunting (Imber & Williams 1968). Approximately 50 individuals from the United States were first released successfully in 1905. These formed a population that initially became established in eastern Canterbury and Otago foothills, South Island (Figure 1.3). The species soon became widespread across the country

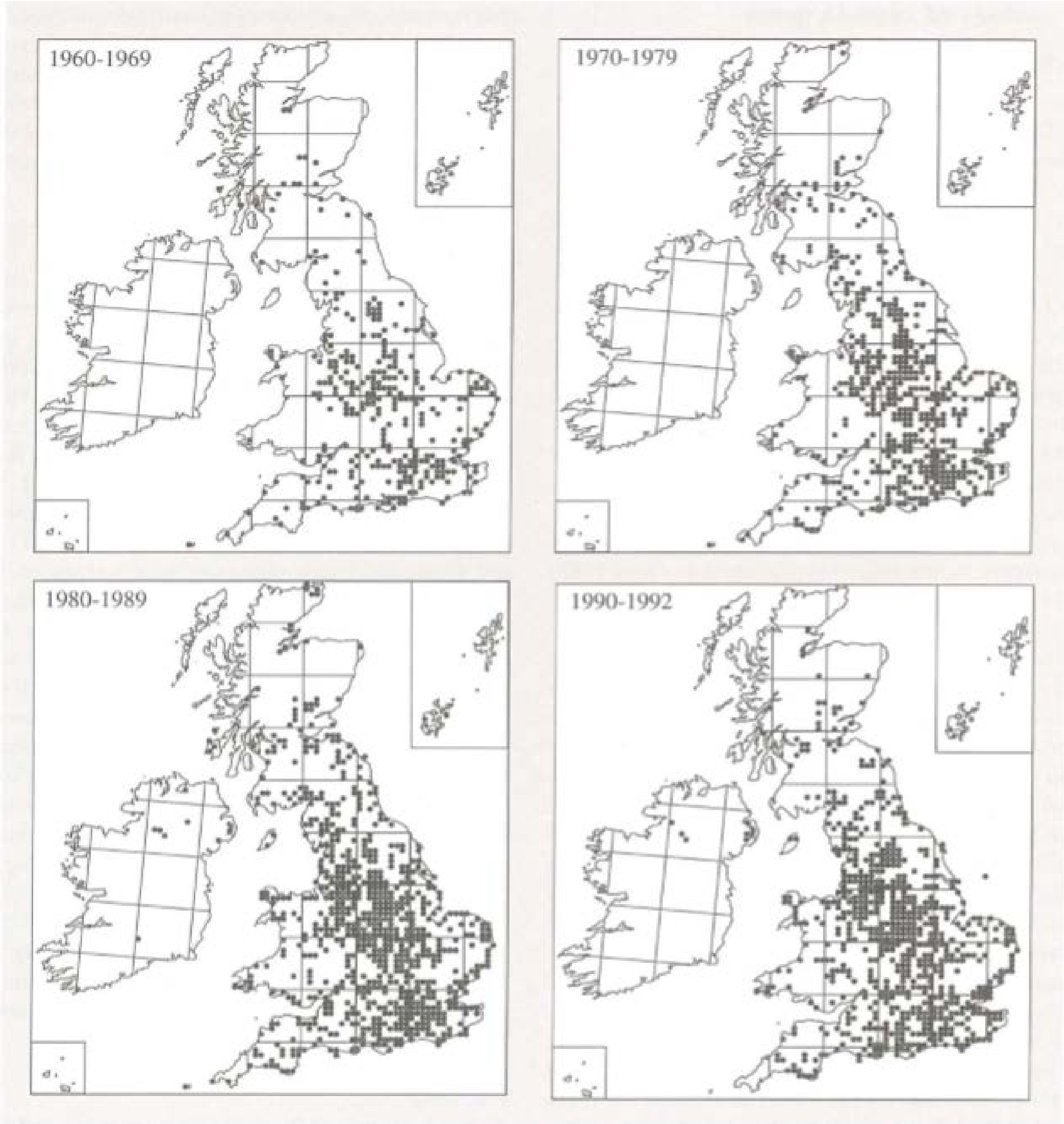

Figure 1.2 From: Allan et al. (1995). Wintering distributions of Canada geese (*Branta canadensis*) during months September to March from 1960-1992. Circles represent 10 km squares that contained sites where Canada geese had been recorded for each 10-year period.

(aided by further releases by the Wildlife Service) and is now abundant nation-wide (Figure 1.3). The eastern slopes of the Southern Alps are considered one of the main breeding areas for Canada geese in New Zealand (Imber 1985). After the breeding season, most of the birds in this population are thought to then move across the Canterbury Plains to lowland coastal lagoons on the Canterbury coast for wintering (White 1986; Marchant & Higgins 1990), utilising the braided-river corridors such as the Waimakariri and Rakaia Rivers to fly down to the coast. In

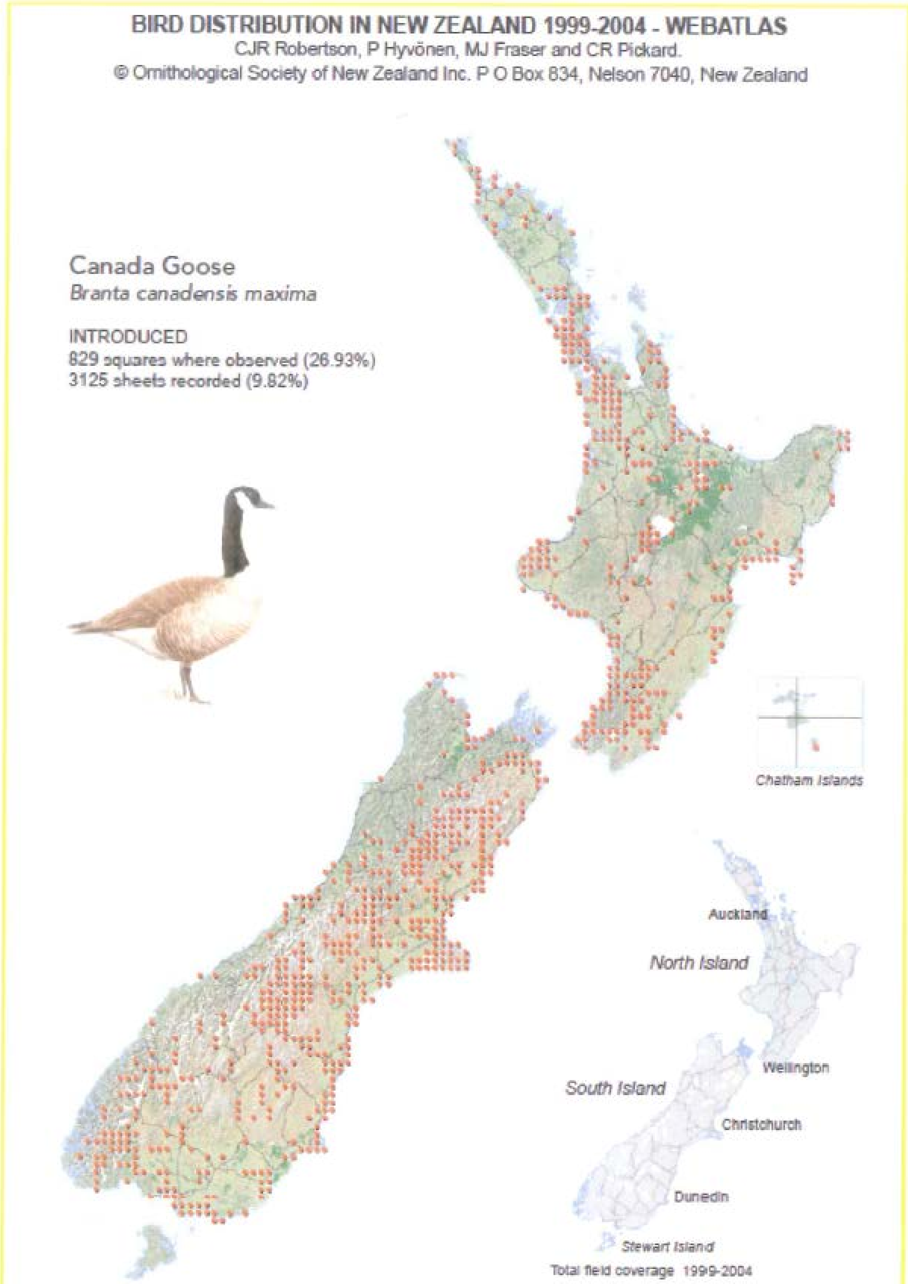

Figure 1.3 Recent distribution of Canada geese within New Zealand. From: Bird Distribution in New Zealand 1999-2004, Ornithological Society of New Zealand.

the 1980's the Department of Conservation performed a banding project on Canada geese and discovered that birds migrated from Lake Ellesmere/Te Waihora to the upper Waimakariri and proximate catchments (Holloway et al. 1987). Therefore, in contrast to their native migrations of north to south in North America, this is a short journey from sea level in the east, to ~900 m above sea level in the west (White 1986; Potts and Andrews 1991; Anderson & Padding 2015).

The population of Canada geese in New Zealand has increased in recent decades. Maloney (1999), for example, found the density of Canada geese significantly increased in 4 of 6 river basins between 1960s and 1990s. Win (2001) investigated foraging behaviours and effects on agricultural yield at Lake Grasmere, in the Southern Alps of New Zealand. He observed 400-450 between March and May, 200-350 from June to September, 10-75 from October to December, and 200-250 from January to February (Win 2001). Thus, this suggests there is a large departure pre- and a large return post-breeding season (Win 2001). Surveys of Lake Ellesmere from 2006-2008 recorded 4899 Canada geese present (Crossland et al. 2015), though as many as 2871 individuals were observed in the Avon-Heathcote estuary in Christchurch between 2009-2010 (Crossland 2013; Crossland 2018: unpublished data). Nevertheless, the number of geese in a specific area can exhibit high levels of seasonal variation.

In the Christchurch area, there are two annual influxes that can affect the local population size: the first occurs during November and December when the resident population is increased both by the production of immature juveniles as well as the arrival of non-breeders and presumed failed breeders from other populations, and the second occurs during April when adults and young-of-the-year migrate to the coastal wetlands near Christchurch from their alpine breeding grounds to overwinter (Crossland 2013). Smaller populations of Canada geese also occur in urban parks such as those observed at Styx Mill Reserve, Clearwater, Horseshoe Lake Reserve and The Groynes (K. McAnergney, Christchurch International Airport; pers. comm.) but it is not known if these are resident or migratory. It is possible that some populations of geese found in suburban parks remain resident year-round due to the availability of food, including that provided by members of the public. In Britain and Ireland, Balmer et al. (2013) found that with increasing range expansion, while some populations may shift to new habitats, other migratory populations had developed resident behaviours. Nevertheless, non-breeders and failed breeders may undergo exploratory flights ranging 50-100 km during a moult migration that begins about 1 month earlier than breeding geese (Allan et al. 1995). Canada geese moult during the post-breeding period for approximately one month (Allan et al. 1995), coinciding with the formation of their chicks' flight feathers. Non-breeding and failed breeders tend to moult up to a month before breeding geese (Mowbray et al. 2002) and can reside in their own separate groups. Thus, Canada geese in the Canterbury region likely include both migratory and resident birds, a pattern also seen in similar populations of Britain and some parts of their native range in North America.

The implementation of new hunting refugia and wildlife reserves resulted in markedly improved conservation statuses for geese populations in Europe (van Roomen & Madsen 1992). However, population growth and limited refugia space has led to the expansion of geese into agricultural landscapes (Fox & Abraham 2017). Habitat fragmentation by human development over many centuries is marred with the complex effects on other floral and faunal species. The combination of improved conservation policy and monitoring systems observed expansions of wintering ranges and enhanced agricultural exploitation by goose populations (Fox & Madsen 2017). It is fair to expect populations of Canada geese in New Zealand to adapt to future challenges and to also be similarly augmented by the green shifts in conservation and wetland management for the coming decades.

The Canada goose as an airstrike risk

Canada geese have become an increasing concern for civil and military aircraft in the USA because of their large size, flocking behaviour and attraction to airports for grazing (Milsom 1990; Dolbeer, Seubert & Begier 2014). Mowbray et al. (2002) stated that Canada geese populations sit between 3 and 4 million but could have been as high as 8 million individuals.

Other estimates during the period 1970-2012 saw the Canada geese population in North America increase from 1.26 to 5.69 million birds, and not surprisingly, the number of bird-strikes with aircraft increased in parallel. Between 1990-2012, a total of 1403 strikes of Canada geese with civilian aircraft were reported, with half resulting in damages to the aircraft (Dolbeer et al. 2014). By 2002, wildlife-aircraft strikes costed the civil aviation industry over US$1.2 billion per year (Allan 2002). According to Allan (2002), 67% of aircraft collisions with Canada geese result in damage, however not all collisions result in a crash. Arrington (1994), on behalf of the United States Airforce, reported 13,427 aircraft collisions with wildlife from around the globe between 1989 and 1993. In 1995, 24 people were killed when their plane struck several Canada geese at Elmendorf Air Base, Anchorage Alaska USA (Bird 1996). Eleven Canada goose collisions between 1986-89 at Reno-Sparks Airport, Nevada USA, resulted in $250,000 in damages that nearly lead to the closure of the facility following the US Federal Aviation Authority concerns if management strategies were not implemented (Fairaizl 1992). Across the USA, the Canada goose is the most commonly reported species involved with bird strikes with aircraft in areas beyond an airport's boundaries at 327 incidents from 1990 to 2014 (DeVault et al. 2016). In the United Kingdom a study found that 11 strikes involving Canada geese were not randomly distributed throughout the year but peaked during the pre-breeding (4) and the post-moult (7) (Baxter & Robinson 2007). Baxter and Robinson (2007) also noted that many individuals flying over a UK airport were sourced from a single population within a radius of ~20 km; in this study they also tested the removal of cereal crops around the airfield and observed a marked reduction in flyovers by Canada geese.

The populations of Canada geese in Britain and New Zealand both show increased movements prior the breeding season (White 1986; Baxter and Robinson 2007). Further, there have been recent marked population shifts to urban centres and increasing proportions of resident populations of geese (Maccarone & Cope 2004). Numerous Canada goose populations around the globe have adopted residential tendencies in replacement of migratory strategies (Dolbeer et al. 2014). These widespread changes in both population size and migratory behaviour raise significant concerns for the future of airstrike hazards, provided that the number of passengers continues its upward trend in conjunction with goose populations (Figure 1.4). Although a total of 1403 reported goose strikes in 12 years may not seem a major concern given a population of geese in the millions, the growing risk of year-round strikes may increase as geese continue to increase in number and change their seasonal phenology. Thus, with the upward trend of air traffic and increasing geese residency in urban centres there is potential to introduce serious hazards for air traffic.

The potential impact of Canada geese on aircraft was dramatically illustrated in 2009 in New York City, where the collision of an aircraft with a flock of Canada geese nearly resulted in the death of 155 passengers (Marra et al. 2009). Fortunately, the plane landed safely on the

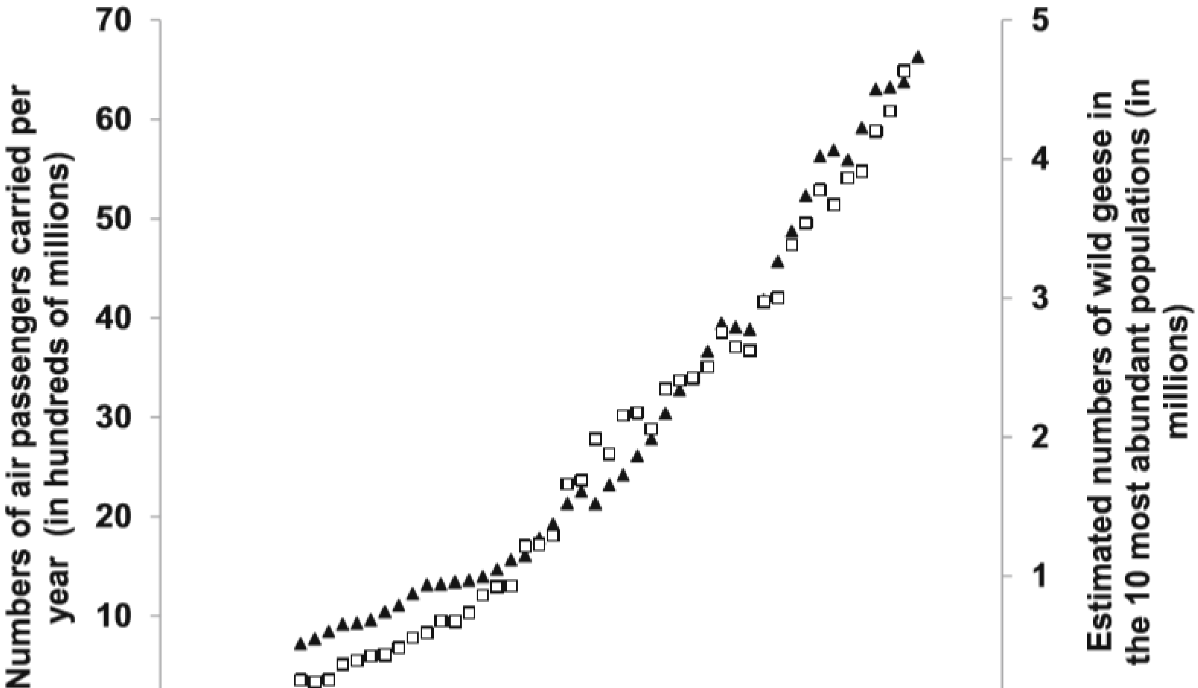

Figure 1.4 From: Stroud et al. (2017). Total annual passengers from 26 European states, 1970-2014 (triangles). Compared with the total estimated abundances of the ten most numerous wild goose populations from 1970-2013 (squares); three populations of barnacle geese *Branta leucopsis,* darkbellied brent geese *B. bernicla bernicla*, Nordic greylag goose *Anser anser*, tundra bean goose A*. fabalis rossicus*, two populations of pink-footed geese *A. brachyrhynchus* and two populations of greater white-fronted *geese A. albifrons*. Data for air passengers from Wold Bank at http://data.worldbank.org/indicator/IS.AIR.PSGR/countries/EU?page=1&display=default

Hudson River and there were no casualties. As a response, natural and man-made habitats and parks within 11km of the three large New York and New Jersey airports were targeted for Canada goose control. Thirty properties were identified as high-risk for aviation and removal of 3,658 moulting geese took place from 2009 to 2013 (DeSisto 2014). Nonetheless, airstrikes prior to this event averaged 159 per year at these two airports, but that climbed to 299 within the following 6 years. This begs the question whether the strategy of culling thousands of birds had assisted in reducing the risk.

Apart from lethal control, soft and passive controls of Canada geese have been used. For example, in Anchorage, Alaska the use of horns, sirens, crackers and screamers, propane cannons, scare crows, and coyote figures (collectively considered 'hazing'), were used to deter geese from the airport vicinity, but were found to be relatively ineffective as ~25% of individuals from targeted populations continued to visit the three airports during the breeding season (York et al. 2000). Although hazing had successfully deterred ~75% of geese, York et al. (2000) stated concerns that increasing habituation to such control attempts suggest that the efficacy was limited.

Canada geese are now classified as 2nd highest strike risk for any bird species in the United States (DeVault et al. 2018). Given the risk posed by Canada geese and similarly large waterfowl, there is a need for airports, including those in the introduced ranges of Canada geese, to collect information on goose movements and population dynamics in their local area. This will provide systematic evidence so that goose strikes can be minimised by habitat management (Bradbeer et al. 2017), applying deterrents, and optimising sites for local lethal controls (e.g., culling of adults, oiling of eggs to reduce productivity). The increasing number of Canada geese in New Zealand raises the possibility that the risk of bird-strikes involving this species is likely to increase in the future.

Feeding Behaviours of Canada geese.

The movements and distribution of geese, especially around sensitive areas such as airports, likely depends on their ability to find and exploit local foraging opportunities. Thus, minimising risk of birdstrikes to aircraft would benefit by determining the behaviours of local populations of Canada geese, and how this varies in relation to foraging habitat across the seasons. A study on foraging behaviour by Fox and Abraham (2017) suggested that wild geese populations may exhibit reduced density dependence as a result of increased food sources granted by year-round modern agricultural landscapes. In contrast to the marked declines observed in wild bird populations across farmland habitats in Europe and North America (Reif 2013; Pe'er et al. 2014), geese in the northern hemisphere show increased abundance associated with farmland, possibly related to increased food availability and wintering on agricultural landscapes (Fox and Madsen 2017). Rising goose populations in these heavily altered landscapes is likely a result of higher energy and nutrient content in agricultural crops that are superior and in greater abundance to the natural foods available to geese (Fox and Abraham 2017). Furthermore, Fox and Abraham (2017) emphasise that contemporary farmland practises in Europe and North America has contributed to improved reproductive successes of wild geese as well as providing a greater carrying capacity for wintering populations. Thus, airports located near areas of agricultural land are likely to face increasing pressure from expanding goose populations.

There is currently little information on the behaviour of Canada geese on New Zealand farmlands. On a farm in the Canterbury high-country, Win (2001) found that over a single year the Canada geese numbers ranged from 10 geese in October/November to a maximum of 400 in March. Over the 69-ha farm, paddocks adjacent to Lake Grasmere were significantly reduced in production by goose grazing, particularly during late summer and early autumn (Win 2001). Additionally, it was observed that neither time of day nor season had any marked effect on foraging intensity; the main determination of grazing pressure on paddocks was abundance of geese. Considering this investigation was performed nearly 20 years ago a new assessment of foraging behaviours is warranted, particularly in the area around Christchurch airport, which comprises a matrix of agricultural land, pastures, sediment-works for construction industries and recreational areas.

The diet of Canada geese has been well studied in several places across their native and introduced range (Buchsbaum, Wilson & Valiela 1986; Heather & Robertson 1996; Win 2001; Fox & Abraham 2017). They are primarily herbivorous but will take a wide range of species, including many agricultural crops (e.g. clover, lucerne, turnips, native and exotic grasses, oats and barley) as well as grazing on pastures (Potts & Andrew 1991; Win 2001). However, Canada geese are inefficient at digesting plant materials compared to many vertebrate ruminant herbivores; Buchsbaum, Wilson & Valiela (1986) found that Canada geese only digested ~37% of total organic matter. With the growth in agricultural intensification and shift towards intensively managed grasslands (with high fertilise use) as a result of the increasing dairy industry in New Zealand, this change in quality in vegetation may have ushered a shift in foraging behaviours of Canada geese across the Canterbury region. Thus, there may be ramifications for airstrikes presented by the changing movements of Canada geese in-part determined by the altered vegetational landscapes in this region of New Zealand.

In addition to changes in the agricultural landscape of Canterbury, a series of earthquakes affecting Christchurch city in 2010-2011 led to the creation of a "red zone", of ~450 ha of land that was classified as uninhabitable following the subsidence and substrate damage of land along the Ōtākaro /Avon River network (Tait, Vallance & Rutherford, 2016). This formerly built up area has now reverted to a series of open paddocks of grass, maintained monthly by the city council. Unintentionally, the red zone has provided urban populations of Canada geese with additional foraging habitat situated next to several wetland reserves; Travis Wetland Nature Heritage Park, Lake Kate Sheppard, and Horseshoe Lake.

Christchurch City Council Regional Parks Teams have monitored Canada goose populations around the city for the last two decades. After the 2010/2011 earthquakes, Regional Parks Teams surveys (Crossland 2018, unpublished data) showed that most Canada geese were residing in the Avon-Heathcote Estuary, ranging between 350 and 4000 birds. The Travis Wetland population ranged between 151 and 1121 individuals. The red zone areas that were not fully cleared of buildings till several years later, but when surveys of geese began in April 2015, the population ranged between 10 and 66 individuals (Crossland 2018, unpublished data). Preliminary surveys conducted in this investigation have observed large flocks of up to 400 individuals, indicating the red zone population is increasing. It is important to consider that despite shifts in agricultural practices in the Canterbury Plains over the last several decades, Canada geese populations are still present within the central city and especially along the Avon/Ōtākaro River Corridor. Assumptions that the seasonal shifts of Canada geese to forage outside of the city during cold or dry bouts (Spurr & Coleman 2005; Dorak et al 2017) should be treated with caution as they tend to be based on international evidence. With an increase in wetland and 'red zone' environments across Christchurch city, the Canada geese may exhibit changes in their foraging behaviour and movements in response to the landscape changes. As seen in Britain, mainland Europe and North America, riparian planting and wetland restoration efforts have led to increases in goose populations (Allan et al. 1995; Anderson & Padding 2015; Fox & Madsen 2017).

An investigation into the activity budgets of urban goose populations in Christchurch city is warranted due to (1) Canada geese being an introduced pest species and (2) no activity budget of urban Canada geese being performed before in New Zealand. Providing a 12-month activity budget of geese from Christchurch will give insight into their behaviours and how they vary across seasons. There may be considerable variation in seasonal activity budgets that could assist in explaining for Canada goose movements within the region. Lastly, fitting GPS-tracking collars to Canada geese would allow for continued behavioural and environmental data collection that could assist in explaining the variations of activity budgets through the 12-month period. However, manipulating animals and fitting them with permanent devices could present effects to behaviour and therefore present an issue of biased data compared to non-tagged individuals.

Risks and Benefits of Tracking Devices

Animal welfare concerns with the use of wildlife tracking devices have steadily increased despite the advancement and improvements to tracking technologies (Sergio et al. 2015; Thaxter et al. 2016; Weiser et al. 2016; Bodey et al. 2018). Concerns focus primarily on the size and attachment mechanisms of the tracking devices and how this may impact behavioural, demographic and physiological responses of manipulated animals (Gessaman & Nagy 1988; Schmutz & Morse 2000; Wilson & McMahon 2006; Casper 2009; Bowlin et al. 2010; Enstipp et al. 2015; Weiser et al. 2016). In recent years, there have been further concerns that even established guidelines on tag size may lead to negative behavioural consequences for the animal (Bodey et al. 2018). These include device-drag that can affect long-distance migratory species (Bowlin et al. 2010; Vandenabeele et al. 2015; Wilson et al. 2015), survival and parental care (Bodey et al. 2018) and imbalance of animal movements (Vandenabeele et al. 2014). A general guideline in the literature is that the total mass of a tracking device, including a collar or harness, should sit between 3 and 5% of total animal body mass. However, this arbitrary standard has been questioned. Barron, Brawn & Weatherhead (2010), Vandenabeele et al. (2012), Weiser et al. (2016), and Bodey et al. (2018) have all criticised the over-liberal use of an arbitrary device-mass standard.

Sergio et al. (2015) found that <10% of investigations in which an animal was fitted with markings and devices failed to incorporate any assessment of the behavioural impacts that may be incurred. The rapid increase in the number of devices with novel and improved technologies is adding to the problem. Although such technologies present a wealth of resources for ecological and behavioural investigation in the wildlife-tracking arena, these new devices are seldom thoroughly tested in large-scale and long-term applications across a range of species in their natural environment (Sergio et al. 2015). This warrants a study into the effects of GPS-collars on Canada geese in New Zealand.

GPS tracking devices are primarily used to collect locational fixes of the desired animal as it moves. Device capabilities tend to be dependent on their size, mainly their total mass. The larger the intended study animal means you are usually able to incorporate more functionality in the form of additional sensors. Temperature, air pressure, light intensity and three-axis accelerometers are the most common sensors beside GPS. Velocity and altitude (above sea level) are post-hoc calculations performed by the devices utilising the GPS-location data. The information provided by these types of devices would allow for higher detailed analyses of Canada goose presence within Christchurch and Canterbury.

1.1. Aims of the thesis

The general aim of this thesis is to study the behavioural, spatial and temporal patterns of Canada geese within Christchurch and the central Canterbury region of New Zealand. Utilising GPS/GSM tracking technologies and direct observational methods the following objectives will be included within the scope of this investigation:

- To assess the effect of GPS/GSM tracking devices on the behaviours of Canada geese;
- Determine mean population, density and activity budgets of Canada geese across varying habitats through diurnal and seasonal phases across a 12-month period;
- Describe the patterns in flight altitude and velocity, and movements of Canada geese collected by GPS tagged individuals to determine their spatial distribution in the region across the annual cycle.

These three objectives are each treated in a separate chapter that follows (Chapters 2 to 4). I have written them as stand-alone chapters in anticipation of submitting them for publication in scientific journals.

CHAPTER 2

EFFECTS OF GPS TAG AND NECK COLLARS ON CANADA GOOSE BEHAVIOUR

2.0 Introduction

Animal welfare concerns with the use of wildlife tracking devices have steadily increased despite the advancement and improvements to tracking technologies (Sergio et al. 2015; Thaxter et al. 2016; Weiser et al. 2016; Bodey et al. 2018). In recent years, there have been further concerns that even established guidelines on tag size may lead to negative behavioural consequences for the animal (Bodey et al. 2018).

A recent study on captive Canada geese (*Branta canadensis*) tested the differences between tags fitted to neck-collars versus attachment as a backpack (Kolzsch et al. 2016). Kolzsch et al. (2016) found that birds exhibited a number of signs of discomfort from both types of tags, but the observation period only lasted 6 days per trial and it was not determined how long it would take for birds to become habituated and their behaviour return to that of unmarked birds. For any study of wild birds, it would be prudent to exclude any data preceding the habituation to a device to avoid any behavioural abnormalities compared to non-tagged conspecifics. In another study, 41 Canada geese were fitted with GPS-collars in Illinois, USA, however no direct observations of tag-effect were performed (Dorak et al. 2017). In a study of neckbands fitted to pink-footed geese (*Anser brachyrhynchus*) at varying temporal scales, changes in body condition immediately following manipulation were found but only minor effects were exhibited over seasonal scales (Clausen & Madsen 2014). Immediate effects were attributed to the stress of handling during the fitting of the neckbands, suggesting the birds eventually become habituated to the neckbands and their behaviour resembles that of unbanded birds. Important questions remain, however, on the long-term effects of tracking devices on survival, movement patterns, reproduction and mate acquisition. Further long-term studies are needed to determine whether the results of tracking studies are potentially biased by the negative effects of the neckbands.

Animals that undergo long-distance migration or seasonal movements may be especially susceptible to the negative effects of a fitted device (Barron et al. 2010). The increased drag and weight of a device has led to decreased return rates of small migratory species, suggesting the devices caused higher rates of mortality (Bowlin et al. 2010). Given differences between species in body size, wing shape and movement patterns, species-specific testing of devices is needed so that any behavioural and physiological responses are known, and adjustments made to either the size or attachment location. Ideally, tracking devices should have little adverse effects, provide reliable data, and minimise any cost to animal wellbeing.

Canada geese were introduced to New Zealand in the early 20th Century, and the population increased rapidly from approximately 50 individuals to 50,000 within 80 years (Spurr & Coleman, 2005). The species is now found nationwide and is of increasing concern due to the damage to agricultural crops and bird strike risk around airports. However, the current understanding of Canada goose behaviour on a spatial and temporal scale in New Zealand is limited. Utilising tracking technologies to improve the understanding of distribution and seasonal behaviours of Canada geese would assist with management plans regarding airstrike hazards, public disease risk and agricultural damage. This need has taken on increased urgency since the end of Canada goose management on a national scale, and local increases in geese populations, such as in the Christchurch City and Canterbury region.

Aims

This study investigated the effect of neck-collar GPS transmitters on the behavioural responses of Canada geese within Christchurch city. The year-round and easily accessible populations of geese in this area provided a convenient opportunity to observe and record behavioural data on geese fitted with collars and compare these to non-collared control birds on a weekly basis for an entire year. In many studies that incorporate satellite-based tags the investigators rarely get an opportunity to monitor any behavioural changes as their target species migrates long distances or inhabit rural and inaccessible environments. Improved understanding of the effects of tracking devices will assist future management of Canada geese worldwide and for any additional deployment of GPS satellite instruments on similarly sized birds.

2.1 Methods

A total of 135 Canada geese (*Branta canadensis*) were captured during their annual moult at Lake Kate Sheppard, Christchurch City, New Zealand on 4 January 2019. The geese were herded onto the lake shore and held in a fenced pen until tagged and/or banded. Due to the sunny and

Figure 2.1. Attachment of Debut-35 GPS tracking device with 38 mm diameter collar.

hot temperature, only 66 geese were banded and after approximately 40 minutes the remaining birds released to prevent overheating and excessive stress. Of the 66 geese banded, 4 geese were also fitted with Debut-35 GPS/GSM tracking collars (Druidtech; 34.5 ± 0.2g including 38mm collar). GPS devices were attached via a neck collar on the base of the neck (Figure 2.1). Device total weight was equivalent to 0.69% of an average 5 kg goose. The collars consisted of two parts that snapped together, requiring less than a minute to install. Most of the 62 other geese were fitted with unique colour combinations of leg-bands to allow individual identification. Geese were released onto the lake immediately after processing. No animals were injured, and all swam away normally after release. A period of two weeks for device- tag-habituation was implemented to allow geese to become familiar with the devices/bands and to allow a rest period following capture.

Devices operate on the Global System for Mobile Communications (GSM) platform that enables constant monitoring of devices provided that they are within range of a cellular communication tower. Within Christchurch City there was fairly consistent coverage, and this allowed me to relocate birds at regular intervals to conduct behavioural observations. With a mobile device the Druidtech-application can be used monitor goose movements and alter fix-rate, behavioural data-rate, and communication-rate.

To compare tag-effect between tagged and non-tagged geese, instantaneous sampling was used (Altman 1974). Bouts were targeted on the four tagged geese by using the GSM to pin-point locations of devices. To compare the behaviour of banded and tagged geese with control geese (no collars), I observed both categories of geese at the same site and time. I also located goose populations in a series of wetlands, lakes, the Avon River, and grassy paddocks in the red zone of Christchurch (an area formerly occupied by suburbs but now abandoned after earthquakes in 2010-11). For each population a goose was chosen using a random number generator that would select 1-in-x geese present. A 10-minute focal-animal watch of behaviours was performed on both the collared geese and the non-collared random individual (Table 2.1).

Depending on the size of the flock present, 2 to 4 individuals would be observed. Total sample sizes were categorised for tagged and non-tagged birds. Following the habituation period, observation bouts were performed every 3-10 days throughout the year, including geese across all habitat types.

Table 2.1. Seven behaviour classes for Canada goose instantaneous sampling.

Behaviour	**Description**
Foraging	Head and neck below level of goose's back; pecking vegetation with bill
Preening	Grasping and moving feathers; shaking and fluffing
Sleeping	Head buried in feathers, no movement
Sitting	Motionless, on the ground/water on its feet or belly, but head and neck raised above level of back
Vigilance	Goose is upright, observing surroundings, neck elongated
Moving	Goose is walking/paddling, but not aggressive, courting, or calling
Interaction	Displays between geese or towards another species; aggressive, courting, vocalising

Statistical analysis

For each goose, behaviour classes were transformed into percentages of total activity for each 10-minute focal-animal watch. When more than one non-tagged goose was recorded from the same flock, observations were averaged to create a single percentage value for each behaviour class. These percentages were then returned to a numeric state between 0 and 1 for statistical analyses in R-studio (RStudio Team 2008). Leg-banded geese were grouped with non-GPS-tagged geese as there were not enough observations to use them as a separate control treatment.

Foraging and moving were the only behaviours with enough data to perform a linear mixed effect model (lmer) to determine differences between GPS-tagged and non-GPS-tagged geese with uniquely tagged geese (*individual*) as a random variable. Functions of lmer are derived from *Lme4* version 1.1-21 package. Habitat type was a fixed effect to control for differences in behaviour between various sites of Canada geese. The presence of GPS-tag (*Tag*) was included as this was the main component of investigation determining its effect on behavioural responses. The individually unique names of GPS collars fitted to Canada geese were treated as a random effect to account for the limited number that were available and because the geese were observed multiple times during the year. Lmer models were constructed with season and diurnal phases as factors to assess temporal effects on criterion scores. When utilising the MuMIn package v1.43.6 to compare models both season and diurnal phases were excluded from analyses as Akaike criterion scores (AIC) suggested a better overall model. Following model selection with lmer function, foraging and movement activity budgets were analysed: tagged and non-tagged geese were compared using Type II Wald chi-square tests. To investigate if habitat type explained differences in behaviour the lmer model fitted with restricted maximum likelihood (REML) t-tests, using Satterthwaite's method, was used to summarise effect of habitat.

Behavioural categories with low percentage values as averages were analysed with the lmer model but the low data and model complexity presented a 'singular fit issue'. The random factor could not be removed from the model as it accounts for pseudoreplication in the data. After checking histogram plots the data exhibited a Poisson distribution. A Poisson model was applicable and so these data values were analysed with a Generalised Linear Mixed Model fitted with a Bayesian framework of Markov chain Monte Carlo techniques (MCMCglmm) using a similar framework as the lmer model. Functions of this package are derived from *MCMCglmm* version 2.29 package (Hadfield 2010). This second model bootstraps the data and all models were specified to 100,000 iterations; 10,000 of the first were burned and the thinning interval was 10. For the behaviours requiring MCMCglmm analyses, several models were tested that included diurnal phases, seasonal phases, habitat, and individuals as random factors and Tag and habitat as fixed factors. Two MCMCglmm models have been utilised to include habitat as a random and fixed effect to present habitat effect on behaviours alongside any effect of Tag manipulation. Both models were compared with MuMIN with a Bayesian Information Criterion (BIC) using the model select function and returned near similar scores.

2.2 Results

A total of 414 observation bouts on Canada geese were performed between January and November 2019. When multiple bouts at the same site were averaged, a total of 258 observation bouts were used to compare between collared (68 bouts), banded (16 bouts) and control birds (174 bouts) (Tables 2.2, 2.3 and 2.4).

Table 2.2. Summary of number of observation bouts made on Canada geese in relation to season. Figures are given for number of bouts for geese with tags, leg-banded only, and non-tagged categories.

Treatment	Spring	Summer	Autumn	Winter	Total
Tag	13	13	24	18	
Leg-band	3	6	4	3	
No tag	64	20	40	50	
Total	80	39	68	71	258

Table 2.3. Summary of number of observation bouts made on Canada geese in relation to diurnal phases. Figures are given for number of bouts for geese with tags, leg-banded only, and non-tagged categories.

Treatment	Morning	Midday	Afternoon	Total
Tag	13	37	18	
Leg-band	1	8	7	
No tag	36	88	50	
Total	50	133	75	258

Table 2.4. Summary of Canada goose observation data split into habitat types showing tag, leg-banded only and non-tagged categories.

Treatment	Lake	River	Redzone grass	Total
Tag	21	21	26	
Leg-band	3	2	11	
No tag	119	26	29	
Total	143	49	66	258

Four collared birds were observed throughout the year within Christchurch City. In June, one collared bird disappeared leaving three study animals for observations during the remaining 4 months. The device of the missing bird did not indicate mortality or any flight path away from the city, and it is likely that loss of signal was due to a malfunction.

Foraging and moving behaviours

Foraging occupied the largest proportion of activity budgets for all geese, whether tagged or non-tagged, across each of the three habitats (Figure 2.2). Foraging was most frequent in

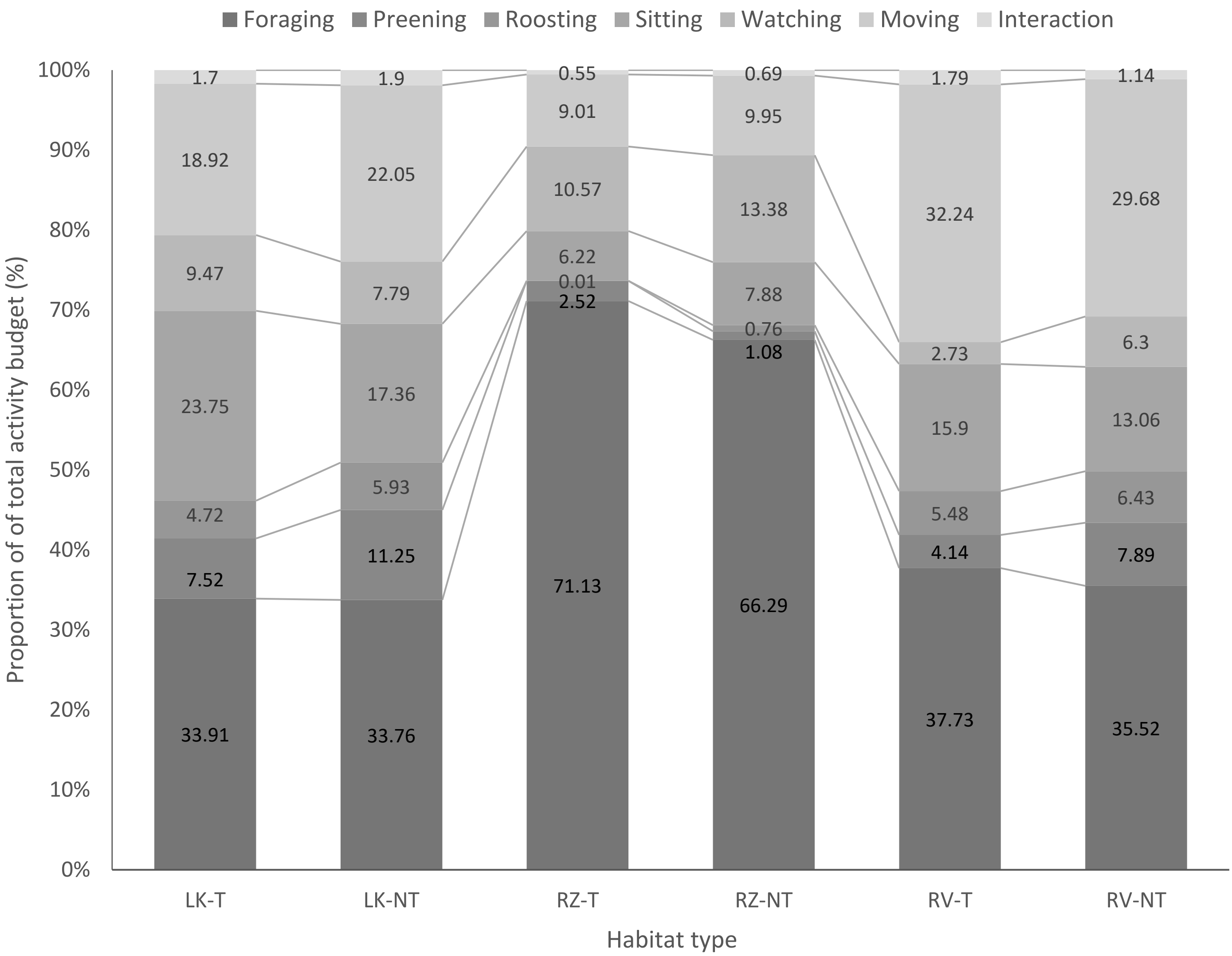

Figure 2.2. Activity budgets of Canada goose in relation to presence of a tag (T) or no tag (NT), and habitat type. For each behavioural category, the mean proportions of time spent in that activity is shown; lake (LK), Redzone grass (RZ) and river (RV). Habitats are further split into compared groups of tagged individuals (T) and non-tagged individuals (NT). Numbers on bars indicate percentages for each behaviour. See table 2.1 for definitions of each behaviour.

Redzone grass paddocks within the central and east of Christchurch City (Mean ± SE, 66.3 ± 0.05 and 71.1% ± 0.06)

and least in lake habitats (33.9 ± 0.06 to 33.8% ± 0.03) for tagged and non-tagged geese, respectively (Figure 2.2). Foraging activity budgets between tagged and non-tagged geese did not differ significantly across all habitats (χ^2 (2, N = 258) = 0.39, $p > 0.05$). Moving was most frequent along river habitats within the central and east of Christchurch City (29.68 ± 0.035 and 32.2% ± 0.039) for non-tagged and tagged geese, respectively (Figure 2.1). Moving was least frequent within the Redzone grass paddocks (9.01 ± 0.032 and 9.95% ± 0.026) for tagged and non-tagged birds, respectively (Figure 2.1). There was no significant difference in movement activity budgets between tagged and non-tagged geese across all habitats (χ^2 (2, N = 258) = 0.038, $p > 0.05$).

Preening, Vigilance, Sitting, Sleeping and Interaction behaviours

Geese exhibited preening behaviours more frequently on lake habitats (Mean ± SE, 7.52 ± 0.03 to 11.25% ± 0.01) and least on Redzone grass paddocks (2.52 ± 0.026 to 1.08% ± 0.02) for tagged and non-tagged geese, respectively (Figure 2.1). Vigilance was most frequent on Redzone paddocks (10.57 ± 0.02 to 13.38% ± 0.017), second on lakes (9.47 ± 0.023 to 7.79% ± 0.01) and least frequent on rivers (2.73 ± 0.023 to 6.3% ± 0.02) for tagged and non-tagged individuals, respectively (Figure 2.1). Sitting was most frequent on lakes (23.75 ± 0.036 to 17.36% ± 0.015) and least frequent in Redzone paddocks (6.22 ± 0.034 to 7.88% ± 0.027) for tagged and non-tagged geese. Interactions were common on both lakes (1.7 ± 0.009 to 1.9% ± 0.004) and rivers (1.79 ± 0.01 to 1.14% ± 0.009) but least common on Redzone paddocks (0.55 ± 0.009 to 0.69% ± 0.007) for tagged and non-tagged geese, respectively (Figure 2.1).

Table 2.5. Outputs of MCMCglmm for preening, vigilance, sitting, sleeping and interaction behaviours exhibited by Canada geese in Christchurch City. Shown are the posterior means, upper and lower 95% confidence intervals, effective sample sizes of the iterations and pMCMC values. BIC scores are also shown. Numbers in bold are significant results.

Model	BIC	Posterior mean	Lower 95% CI	Upper 95% CI	eff sample	*p*-MCMC
Response: preening	771.6					
Intercept		-1.07	-4.22	2.04	9000	0.31
Tag		0.78	-0.15	1.68	7185	0.091
Response: preening	776.9					
Intercept		-0.83	-2.01	0.33	6001	0.15
Tag		0.75	-0.25	1.656	7851	0.12
Habitatlake		0.88	-0.16	1.96	8131	0.099
HabitatRedzone grass		-1.68	-3.02	-0.43	6245	**0.013**
Response: vigilance	1056.1					
Intercept		1.1	-1.27	3.32	9000	0.205
Tag		0.15	-0.36	0.66	7211	0.544
Response: vigilance	1060.5					
Intercept		0.6	-0.59	1.72	8498	0.23
Tag		0.16	-0.36	0.65	7408	0.51
Habitatlake		0.08	-0.43	0.64	7664	0.77
HabitatRedzone grass		1.41	0.85	2.01	7877	**< 0.001**
Response: sitting	1281.2					
Intercept		1.63	-0.21	3.46	9000	0.067
Tag		0.23	-0.17	0.64	8447	0.24
Response: sitting	1286.2					
Intercept		1.84	0.89	2.83	9000	**0.0096**
Tag		0.23	-0.15	0.65	8449	0.254
Habitatlake		0.31	-0.11	0.71	8715	0.14
HabitatRedzone grass		-0.95	-1.42	-0.46	8227	**< 0.001**
Response: sleeping	289.6					
Intercept		-10.11	-16.27	-4.84	2098.8	**0.005**
Tag		4.3	0.14	9.56	757.3	**0.015**
Response: sleeping	294.6					
Intercept		-9.47	-14.86	-4.39	1469	**0.002**
Tag		4.06	-0.27	8.55	923.6	**0.024**
Habitatlake		0.31	-2.64	3.58	5212.9	0.85
HabitatRedzone grass		-4.03	-8.25	0.23	2890.6	0.054
Response: interaction	441					
Intercept		-1.7	-2.83	-0.67	4652	**0.009**
Tag		-0.15	-1.16	0.91	6772	0.737
Response: interaction	444.4					
Intercept		-1.66	-2.94	-0.41	4955	**0.0078**
Tag		-0.38	-1.54	0.72	7448	0.46
Habitatlake		0.47	-0.64	1.61	7614	0.404
HabitatRedzone grass		-0.73	-2	0.58	6996	0.27

For the behaviours analysed with MCMCglmm, only sleeping was significantly different between tagged and non-tagged geese (Table 2.5). Sleeping on lakes was more frequent for non-tagged geese (Mean ± SE, 5.93% ± 0.01; tagged geese 4.72% ± 0.03), on rivers (6.43% ± 0.03; tagged geese 5.48% ± 0.03), and on Redzone paddocks (0.76% ± 0.011; tagged geese (0.01% ± 0.013). However, the differences were small in terms of the total time budget.

Foraging activity was significantly larger in Redzone grass paddocks than the river and lake habitats (estimate = 0.321 ± 0.0476, $t_{163.58}$ = 6.742, p < 0.001) (Table 2.6). Frequency of moving was significantly less common in lakes (estimate = -0.095 ± 0.0289, $t_{207.73}$ = -3.31, p = 0.001) and Redzone paddocks (estimate = -0.218 ± 0.0319, $t_{205.17}$ = -6.86, p < 0.001) compared with river habitat (Table 2.6). which is supported by observational data seen in Figure 2.2.

Table 2.6. Outputs of linear mixed effects model (lmer) for foraging and movement behaviours exhibited by Canada geese in Christchurch City. Shown are the estimates, standard errors, degrees of freedom, t-values and p-values. AIC scores for each model are also shown. Numbers in bold are significant results.

Model	AIC	Estimate	Std. Error	df	t	p value
Response: foraging	41.2					
Intercept		0.38	0.0466	5.84	8.218	**< 0.001**
Habitatlake		-0.296	0.043	164.07	-0.688	0.492
HabitatRedzone		0.321	0.0476	163.58	6.742	**< 0.001**
TagN		-0.026	0.0414	5.487	-0.625	0.557
Response: moving	-167.8					
Intercept		0.309	0.035	5.91	8.89	**< 0.001**
TagN		0.006	0.031	4.94	0.19	0.854
Habitatlake		-0.095	0.0289	207.73	-3.31	**< 0.001**
HabitatRedzone		-0.218	0.0319	205.17	-6.86	**< 0.001**

2.3 Discussion

From this investigation I determined that six of seven behaviours did not show any significant behavioural differences in Canada geese fitted with GPS-collars compared to geese without collars. This indicates that the collar tracking devices had little or no effect on most of the behaviours monitored, and that the use of collars is suited for Canada geese, and perhaps other goose species, with little risk of bias. Foraging, preening and movement behaviours were all found to be similarly expressed between tagged and non-tagged geese. These key behaviours could be considered as high priority considering their potential negative impact on animal wellbeing if they were impacted by the neck collars.

Reduced survival, breeding success and foraging rates have been effects reported in the past as a result of marking animals with foreign objects of varying sizes and mass (Barron et al. 2010). Clausen & Madsen (2014) conducted a study to assess long-term effects of neckbands on migratory geese and found no adverse effects on body mass but questioned whether the neckbands could still affect life histories such as reproduction (reducing attractiveness for example), and survival by increasing the risk of predation. A major concern about utilising GPS trackers for behavioural investigations is that the data collected is trustworthy (i.e. representative of a non-manipulated individual). Knowing the potential effects of any tracking devices is vital if an investigator is to avoid present telemetry data that is biased in comparison to the non-manipulated population. My results indicate that the neck collars I used are suitable for future research on Canada geese in New Zealand, and that these devices appear to have little effect on the behaviour of the birds and thus any data obtained should be representative.

Sleeping was the only behaviour that was found to be significantly different between tagged and non-tagged birds. There are several possible explanations for this pattern. First, it may result from the small sample size, as sleeping was observed only rarely. Secondly, there may be a bias in under-estimating sleeping time in collared birds, as the tracking devices only allowed me to pinpoint their approximate location and non-sleeping birds (i.e., actively moving birds) were likely more readily detected by sight as I searched than a sleeping (and non-moving bird). Thirdly, it is possible that the tagged birds, having been captured and handled by myself, changed their behaviour upon seeing me, and thus were less likely to roost and instead stay alert. Finally, it should be noted that sleeping behaviour was fairly infrequent overall, and the differences I found very small (within a percentage point or two difference). Even if this difference is an effect of the tags, it is not as concerning as would be a significant difference in preening or foraging that may have a greater effect on wellbeing.

I was only able to attach 4 neck collars to geese for my study. Ultimately, the small sample of birds limited by ability to detect subtle changes in behaviour. Due to the unfortunate loss of one bird with a collar due to malfunction, the opportunity for data collection became more limited throughout the year. Thus, it would be worth acquiring more data on the behaviour of geese with and without collars, to determine whether differences in behaviours like sleeping are confirmed, and whether other aspects such as survival and reproductive success are affected as well. Further, having a larger sample of GPS-fitted animals would increase the resolution of any possible device effects and improve statistical analyses.

The Canada geese within Christchurch City provided a great opportunity to investigate any long-term impacts of GPS collars on their behaviours. Geese have been observed for long periods of time with considerations of the diurnal and seasonal phases. This has provided a substantial amount of information for the situation of Canada geese within this region of New Zealand. Due to the concerns surrounding large waterfowl, particularly the persistent population growth of Canada geese, aviation authorities and military air forces worldwide are increasing efforts to assess risk of airstrikes. With a shift from migratory to residential tendencies in Canada geese (Cooleman et al. 2005), and the continued rise in population, investigations must continue to assess these behavioural changes to maintain efficacy of management plans in urban environments (Bradbeer et al. 2017). Utilising GPS collars on Canada geese has expanded our knowledge of how the geese are moving among and within the urban habitats and this investigation has established that this tracking collar can provide trustworthy information.

GPS technologies are increasing in demand and progressing in development at great speed, nevertheless, such speed must be met with rigorous testing and an assessment of their potential effects on the animal. Many investigations utilising GPS tracking devices do not get an opportunity to consistently observe the behaviours of their study species and to determine any detrimental effect to their wellbeing. Despite the important of knowing how a tracking device might affect an animal's behaviour, studies that report such effects are declining by >1% yr^{-1} (Geen, Robinson & Baillie 2019). Only 14/620 papers studying free-ranging marine mammals between 1965 and 2013 examined the effects of GPS-device deployments in a quantifiable manner (McIntyre 2015). The arbitrary standards surrounding telemetry applications usually only concern device-mass and device-drag however, many applications cannot feasibly assess long-term effects of such devices nor make efforts to report such information (Sergio et al. 2015).

This study encountered some difficulty resulting from limitations of the GPS instruments in the field. The devices are solar powered and therefore are dependent on relatively consistent hours of sunlight to maintain optimal operation. When sunlight hours are diminished for several consecutive days the battery limited the rate of data collection and transfer. This meant that locating birds with the tags could often not be achieved at times. Nevertheless, utilising the GSM networks and the device software enabled control of device settings to manage power and avoid long periods of reduced data collection. Devices were also capable of automatically changing device settings according to voltage thresholds in case they were beyond cellular communication range. The prevailing issue with this data communication system is the reliance on the GSM presence by cellular towers. One tagged bird was lost partway through the year, probably due to a device failure. It is expected for device failures to occur but with few study animals to begin with it reduces data resolution considerably. Of the three remaining tagged birds the spring brought new challenges. Devices could be tracked to the nearest 20 meters and up to within 5 minutes of last known location making it easy to find tagged animals for observations. Though in spring the three tagged animals resided in dense foliage and moved between habitats much less, reducing the amount of solar charging. This made it difficult to maintain observational bouts. Interestingly however, at least one of the tagged birds was known to have successfully bred within a wetland reserve indicating that the tag had not affected its ability to nest.

2.4 Conclusions

There was no significant difference between tagged and non-tagged Canada geese for six of seven observed behaviours in Christchurch City. Sleeping presented the only significant difference with non-tagged birds exhibiting it more frequently. Sleeping was one of the least commonly observed behaviours with the vast majority of time for all geese spent foraging across each habitat type. More instalments of these GPS collars would improve resolution of comparisons where there were limited observations for certain behaviour classes compared with non-tagged individuals. Nevertheless, the amount of data collected during this study has provided confidence in the chosen devices and that the telemetry data can be trusted for future investigations.

CHAPTER 3

SEASONAL AND DIURNAL PATTERNS IN THE POPULATION AND BEHAVIOURS OF CANADA GEESE IN THE CHRISTCHURCH CITY REGION, NEW ZEALAND

3.0 Introduction

Population trends of Canada geese in New Zealand

Since their first successful introductions in 1905 there have been fluctuations of Canada goose populations in New Zealand, particularly in the South Island. From less than 5,000 in 1920's (Lamb 1964; Imber & Williams 1968), Canada geese increased to ~20,000 in 1950's (Williams 1981), up to ~24,000 in 1980's (Potts 1984), 36-43,000 in 1997 (Holloway et al. 1997), with 40,000 in the South Island (Heather & Robertson 1996), and during the early 2000's all estimates sat around 45-50,000 individuals (Spurr and Coleman 2005).

In Christchurch City the Regional Parks Team (Christchurch City Council) began surveys of Canada geese populations in 2000 across 27 sites, including the Waimakariri and Avon Rivers and their estuaries, coastal lagoons, urban parks and ponds, wetlands and reserves, oxidation and effluent ponds and red zoned grassy districts. In total there were 71 counts from May 2000 to April 2018, and the total number of geese averaged 2813 (Crossland 2018, unpublished data). The lowest numbers (685-964) were recorded from October and November in spring while the highest numbers (3500-4666) occured from May to August in winter (Crossland 2018, unpublished data). This suggests there is a strong seasonal variation in geese presence within the city and that there may also be ~1000 permanent residents throughout the year. The average number of geese counted from 2000-2010 prior to earthquake sequence of 2010-11 was 2961. From 2011-18, the population dropped slightly to 2443, however, within the last 3 years the average had increased back up to 2919 geese (Crossland 2018, unpublished data).

Following the earthquakes, ~450 ha of damaged suburbia along the Avon/Ōtākaro River Corridor remained uninhabitable, and this land was named the red zone (Tait et al. 2016). Following the final removal of suburban homes on the red zone, the land has since been returning to wetland habitat with assisted riparian planting initiatives. Future plans for the red zone include the re-planting of much of the space to produce a large forest for recreational use and for the increase of local biodiversity. "Greening the Red Zone" has been an incorporated society since 2016 to produce plans for the future of the space (http://www.greeningtheredzone.nz/). As Canada geese use a lot of this land for foraging there could be major shifts in goose presence should the land-use change be considerable.

Outside of Christchurch, the largest populations of Canada geese are found on Lake Ellesmere/Te Waihora (43 ° 46' S, 172° 28' E). Lake Ellesmere is the third largest lake in the South Island at 180 km^2 and is ~25 km south of Christchurch. The population of Canada geese on this lake ranges between 3,000 and 5,000 birds (Crossland et al. 2015), although previous gatherings have been as high as 12,000 (White 1986).

Management responses to Canada geese in New Zealand

During the 20th century, management plans were initiated in conjunction with varying degrees of game hunting restrictions as goose numbers increased in New Zealand (Spurr and Coleman 2005). In 1950-51, the pressure from disgruntled farmers in North Canterbury led to the culling of >4,700 geese and destruction of ~1,150 eggs (Imber and Williams 1968). In 1963, ~6,000 geese were shot at Lake Ellesmere/Te Waihora during a limited hunting season (Williams 1981). In 1976-80, ~9000 eggs were destroyed in the South Island in efforts to curtail population growth (Holloway et al. 1997), and in 1981-89, a further ~14,000 eggs, 600 juveniles and 30,000 adult geese were destroyed (Holloway et al. 1997).

Despite direct and invasive management strategies, population growth of Canada geese remained steady into the 2000's. It is suggested that improvements to agricultural practices in the 1980's such as irrigation, shifts to improved pastoral land and fertiliser availability attributed to increases in Canada geese populations in high country New Zealand (Potts 1984; White 1986; Potts & Andrews 1991; Holloway et al. 1997). As further agricultural land-shifts and land-improvements occur, geese population dynamics may continue to adapt and increase their distribution accordingly. Furthermore, the natural return of the red zone to wetland habitat assisted by riparian planting may further facilitate geese populations in this area.

Habitat and behaviour of Canada geese in New Zealand

There have been few recent investigations into Canada geese in New Zealand, with most being performed during the second half of the 20th century. Several subspecies of Canada geese had been identified as part of the introduced populations within New Zealand. Previously is was considered that common/Atlantic Canada geese (*Branta c. canadensis*) were introduced to New Zealand, but Imber (1971a) and White (1986) suggest that the dominant subspecies released was the giant Canada goose (*Branta c. maxima*) and that they likely interbred with the Atlantic subspecies since being introduced.

Similar habitat found in high-country tussocks and grassy plains found in North America and New Zealand have aided the success of introduced Canada geese as they prefer these habitats (Imber 1971; White 1986). Short distances separate east-coast wetland habitats and high-country breeding areas within the South Island of New Zealand (~ 90 km for much of the coastline), and as the giant subspecies of Canada goose is predominantly sedentary, this close alignment of breeding and wintering area was likely a factor in their success in New Zealand (White 1986). Less migratory behaviour implies more dispersive behaviour and thus less seasonal synchrony among populations. White (1986) notes that within Britain and New Zealand the introduced populations have developed similar movements that are limited to short spring and autumnal flights between coastal lakes (wintering grounds), high-country tussock (breeding grounds), and flights of failed and non-breeders to lakes for annual moults (White 1986). Breeding in colonies has declined as population control strategies during 1970's and 80's

(Holloway et al. 1987) have resulted in geese dispersing to more isolated ranges to nest (White 1986).

With many geese located near to Christchurch there are important implications for their impact on agriculture, airstrike hazards, fouling, and biodiversity. Agricultural impacts by geese have been investigated in alpine pastureland through observations of foraging behaviours (Potts and Andrews 1991; Win 2001). However, little is known about Canada goose time budgets for diurnal and seasonal variation within an urban habitat in New Zealand. Investigating behavioural time budgets of geese within an urban environment may benefit plans for control and mitigate impacts presented by a growing population. Dorak et al. (2017) found that Canada geese inhabiting the Greater Chicago Metropolitan Area (GCMA) were granted sanctuary from hunting year-round. During winter in the GCMA, 85% of the resident goose population remained sedentary, not even venturing to fields for foraging, thus avoiding any risk to survivability (Dorak et al. 2017). While Canada geese can be shot year-round in New Zealand, food-availability may now be less limiting within urban Christchurch with recent increases in green spaces. As in Chicago, Canada geese in urban Christchurch have a permanent sanctuary with little risk from hunters throughout the year.

Aims

My objective in this chapter is to investigate: a) seasonal variations and b) diurnal variations in the behaviour of a population of Canada geese in Christchurch city. The population and behaviours of Canada geese were also studied within 4 habitat types across the study area. Key behaviours such as foraging, moving, sleeping, preening, vigilance and interaction were observed through instantaneous sampling during this period. Transects were also used to observe changes in goose distribution and population throughout the year. Activity budgets were then calculated to describe how Canada geese function within a unique and changing urban New Zealand environment.

3.1 Methods

Observations of Canada geese were performed across 5 transects that were spread within an 8 km radius of the Christchurch International Airport boundary. These transects were labelled:

A. *McLean's Island:* circumnavigates McLean's Island Road to the west and south west of the airport. Pine forest plantations, agricultural pasture and quarrying-industry occupies the lands surrounding this transect. Some gravel roads off this road lead to the Waimakariri River which were traversed to observe any possible geese sitting on the stretch of river islands and riverbanks.
B. *Coutts Island*: to the north and north east of the airport. This road, like McLean's Island, borders the Waimakariri River on its southern banks. It is predominantly surrounded by dairy pasture with some arable croplands. Similarly, it has access to the riverbank to survey geese.
C. *The Groynes and Clearwater*: The Groynes is a Christchurch City Council (CCC) recreational park for dog walking, picnics, fishing and water sports. It has several wildlife ponds that have included the presence of Canada geese in low numbers previously. Clearwater is a private development with residential covenants and a golf club attached adjacent to The Groynes. Within this development there are large ornamental lakes where waterfowl often reside.
D. *Sawyers Arms Reserve/Lake Roto Kohatu*: Two lakes very close to the north east of the airport runways. They are used for recreation, with one lake fully designated as a water-motorsport racing track, and the second a swimming, sailing, paddling lake. Geese have been observed here before and due to its proximity to the airport it was important to assess how many geese visit.
E. *Styx Mill*: Is a conservation reserve run by the CCC within the northern suburb of Redwood. It is a wetland with two small lakes and surrounding pasture for cattle and sheep grazing. Many geese visit these lakes with the majority appearing for the annual

moult in December and January. The lakes are 1.6 km south of The Groynes and 2.7 km east of Sawyers Arms. With many geese frequenting this habitat it was a high priority within this study.

In addition, I made observations on a variety of wetland habitats, urban lakes, red zone grass paddocks and the Avon/Ōtākaro River corridor in Christchurch City, particularly those in the northern and eastern suburbs. Observations were conducted from December 2018 to January 2020.

Instantaneous focal sampling was used to determine individual goose behaviours across the diurnal and seasonal cycle (Altman 1974). Diurnal phases were categorised as morning (before 11 am), midday (11:00 – 13:59 pm) and afternoon (after 14:00 pm). Transects were visited most weeks and presence or non-presence of geese was recorded; when geese were present, 10-minute focal-watches with 15-second intervals were performed for a minimum of two randomly chosen individuals. A random number generator was used to choose geese in flocks. Habitat type, waterbody presence, weather, time and number of geese were also recorded along each transect and at each study-site within the city.

Transect data was categorised into habitat-type along with the other study-sites within the city. These included recreation and wetland reserve lakes, the Avon/Ōtākaro River corridor, agricultural land and red zone grass paddocks. Urban lakes and wetland habitats were grouped together as they both had human presence as well as native riparian planting. All behavioural observations are presented as proportions of activity budgets exhibited by Canada geese throughout the seasons within the city study-sites.

Statistical Analyses

For 10-minute focal-watches, a tally was recorded for each 15-second interval; one of seven behaviour classes was marked accordingly (see Table 2.1 in Chapter 2 for behaviour classes).

Focal watches from each study-site or transect were averaged and converted to a percentage point for each observation bout. These percentages represented a proportion of each behaviour to create an activity budget of Canada geese. Each sample period for a study-site contained an averaged percentage of at least two geese. The activity budgets were used to describe behavioural differences between and among habitats, diurnal phases and the seasons. Recorded goose numbers for this same period of time were utilised to build a density map to represent the changing goose population per hectare that occupied the study-sites.

When normality assumptions were not met due to imbalanced data, the non-parametric Kruskal-Wallis test was performed to analyse seasonal and diurnal variations of Canada goose populations. A Dunn-test (Dunn 1964) was used for multiple comparisons of groups to establish which months, seasons, habitats and diurnal phases were significantly different from one another. Further, a linear model was used to assess Canada geese behaviour among and within habitats over seasonal and diurnal phases. For post-hoc analyses, a test of least square means (*lsmeans* package version 2.30-0 (Lenth 2018)) for multiple comparisons was used to determine which habitats and behaviours significantly differed from one another across the seasonal and diurnal time periods.

3.2 Results

Sampling intensity

A total of 663 study bouts were performed between November 2018 and January 2020. This included 525 focal watches; 139 bouts along transects found no geese, thus no focal watches were performed. Of the 139 bouts where no geese were observed 70 were along agricultural transects (McLean's Island and Coutts Island), and 69 were among urban lakes (The Groynes/Clearwater and Sawyers Arms/Roto Kohatu). The 525 focal watches with geese were averaged according to study-site to produce a final total of 297 mean percentages that were then used to calculate the Canada goose activity budgets.

Agricultural Transects

Of the transect bout with no geese, 30 bouts along McLean's Island and 38 of Coutts Island roads resulted in no Canada geese being observed. As a result, no focal watches were performed in this habitat type and so no further statistical analyses were conducted. These results indicate that Canada geese did not occupy these sites throughout the year, which are located in high-risk areas close to the airport.

Seasonal Variation in population size

Across the four seasons, the highest mean number of geese were observed in summer (93.58±7.9) and lowest during spring (25.49±5.5) (Figure 3.1). Highest mean number of geese observed was during winter in June (143.7±28.4) and the lowest was in spring during October (13.5±2.5) (Figure 3.1). Seasonal variation between winter and spring showed a significant reduction in geese number ($Z = 4.6$, $p < 0.001$), and subsequently, there was a significant increase in geese between spring and summer ($Z = 8.39$, $p < 0.001$).

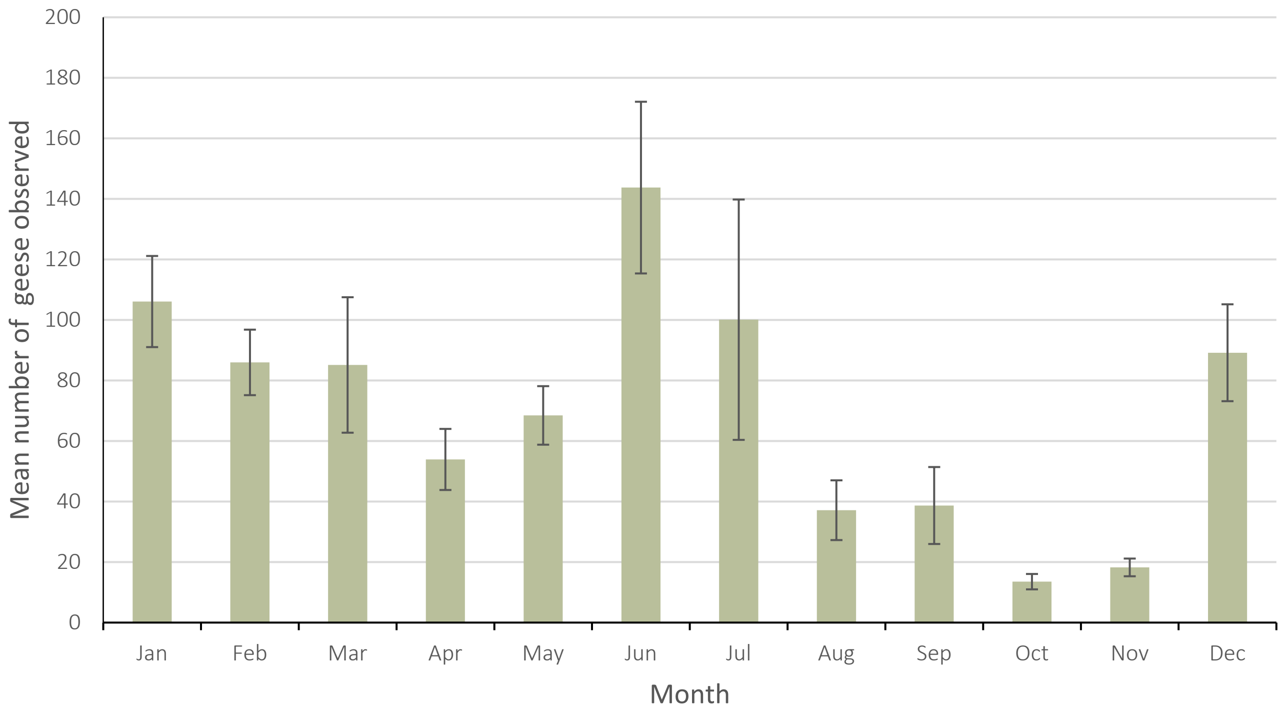

Figure 3.1. Seasonal variation of Canada goose numbers across all visited sites in Christchurch City from January 2019 to December 2019. Standard error of the mean observations are shown for each month.

There were considerable increases in the mean number of geese observed from May to June (+75.3), and November to December (+70.9) (Figure 3.1). A similar decrease in mean number of geese was observed between July and August (-63). However, there was only a statistically significant increase in geese between November and December ($Z = 3.37$, $p = 0.0025$).

Population size in relation to habitat and season

The highest mean number of geese were observed in red zone habitats (105.8±10.2) and lowest was in river habitats (38.6±6.99) (Figure 3.2). Highest mean number of geese were observed in red zone habitats during Winter (152.6±36.8) while the lowest was in lake habitats during Spring (10.6±1.49) (Figure 3.2). red zone habitats had significantly more geese than lake habitats on average ($Z = 5.44$, $p < 0.001$). Similarly, the red zone had significantly more than in river habitats on average ($Z = 4.89$, $p < 0.001$).

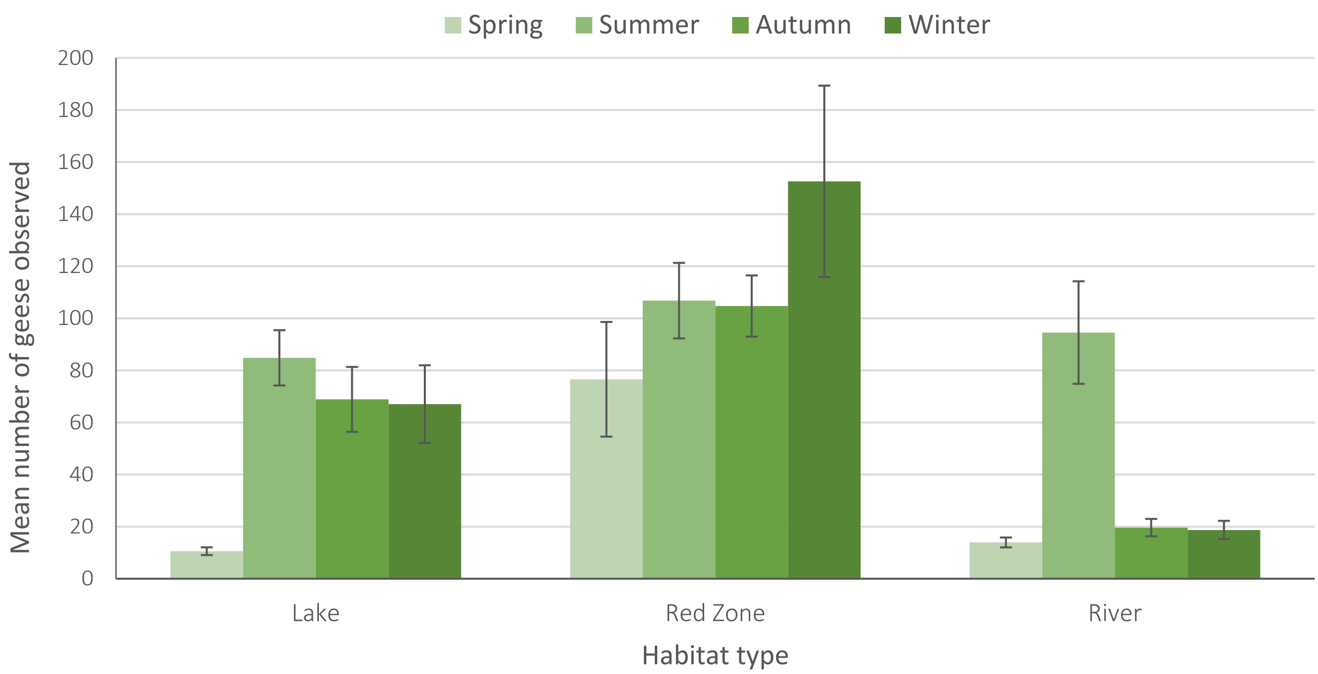

Figure 3.2. Seasonal variation in mean number of Canada geese across lake, red zone and river sites visited in Christchurch City, 2019-2020. Standard error of the mean values are shown for each habitat types.

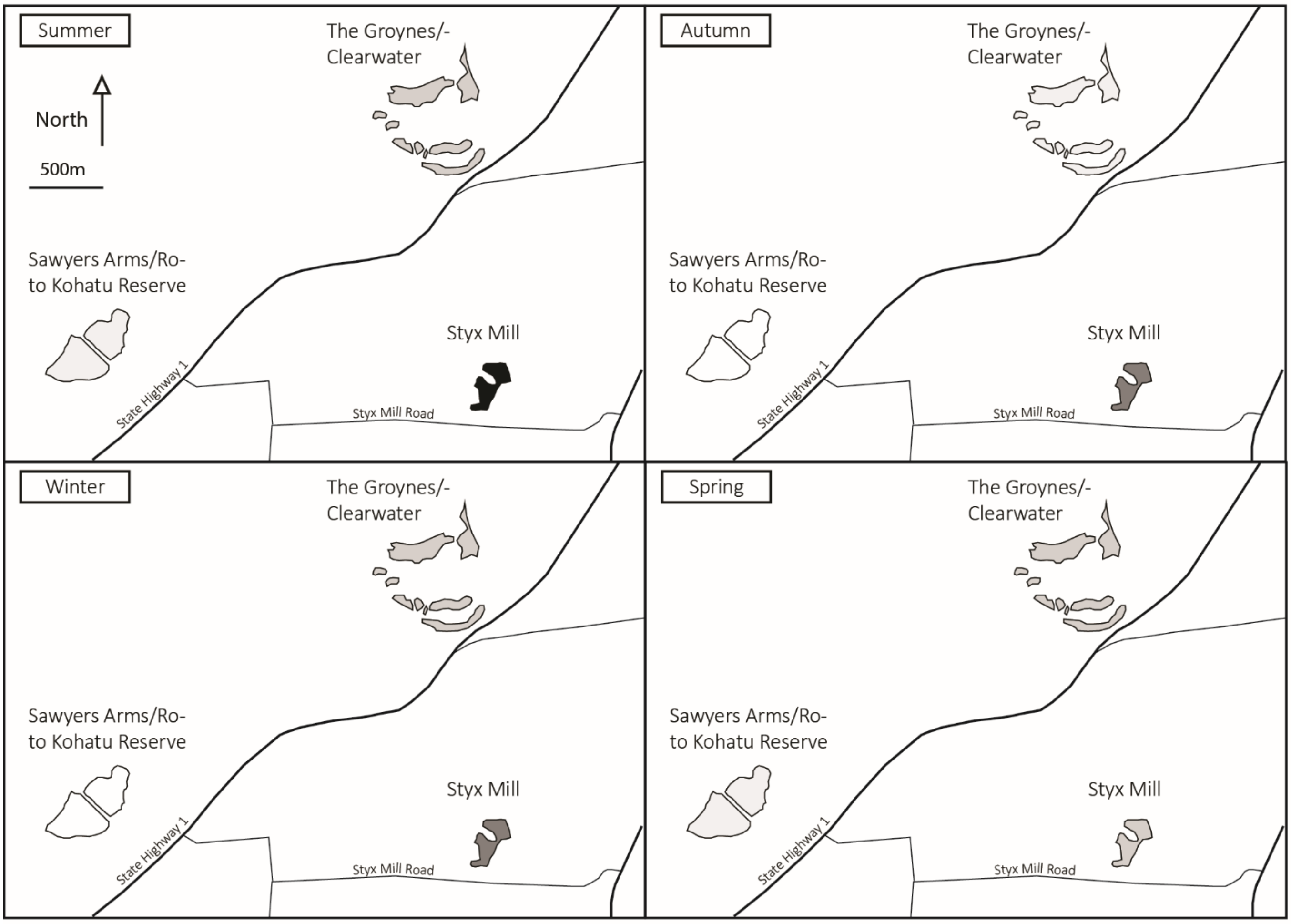

Figure 3.3. Trace map showing seasonal variation in Canada goose density across three transect sites in north west Christchurch City from December 2019 to January 2020.

In Spring, there were significantly more geese in red zone habitats than in lakes (Estimate = 66.01, SE = 17.8, t_{285} = 3.7, p = 0.014). In Summer there were no significant differences between goose populations among habitat types. For Autumn, there were significantly more geese in red zone than river habitats (Estimate = 85.1, SE = 22.1, t_{285} = 3.89, p = 0.008). Finally, in Winter there were significantly more geese in red zone than river habitats (Estimate = 133.9, SE = 26.2, t_{285} = 5.1, p = < 0.001) and in red zone than lakes (Estimate = 85.5, SE = 21.9, t_{285} = 3.91, p = 0.006).

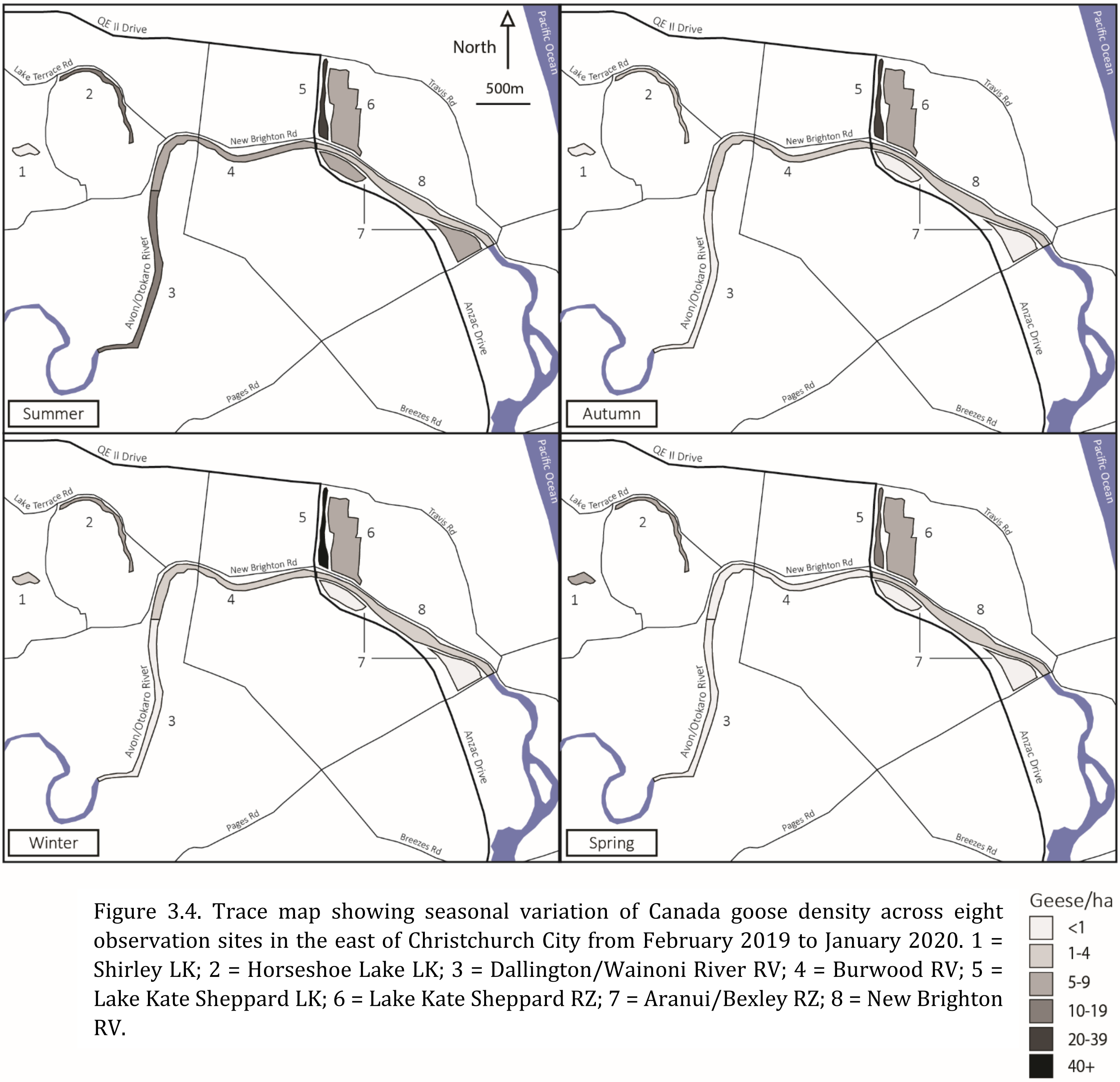

Figure 3.4. Trace map showing seasonal variation of Canada goose density across eight observation sites in the east of Christchurch City from February 2019 to January 2020. 1 = Shirley LK; 2 = Horseshoe Lake LK; 3 = Dallington/Wainoni River RV; 4 = Burwood RV; 5 = Lake Kate Sheppard LK; 6 = Lake Kate Sheppard RZ; 7 = Aranui/Bexley RZ; 8 = New Brighton RV.

The transects to the north west of Christchurch city showed that geese were most widespread during summer and spring with all three habitats containing geese (Figure 3.3). The density of geese ranged from <1 goose/ha at Sawyers Arms/Roto Kohatu (a max of 4 geese were observed here on one occasion in spring) to >40 geese/ha at Styx Mill. The highest density was observed during summer at Styx Mill Reserve (52.2 geese/ha) but this site also maintained relatively high densities of Canada geese during autumn and winter (19.1 and 10.1 geese/ha respectively) and only dropping in spring (1.9 geese/ha) (Figure 3.3).

Density estimates in the north east side of Christchurch city showed that geese were most widespread during summer with 7 of 8 sites containing > 1 goose/ha (Figure 3.4). On lakes, the density of geese was highest during winter at Lake Kate Sheppard (79.1/ha) and for summer and spring this lake still had > 20 geese/ha. Horseshoe Lake had > 1 goose/ha throughout the whole year with its highest density in summer (15/ha) and lowest in autumn (3/ha) (Figure 3.4).

On red zone grassy areas, the density of Canada geese ranged from < 1 at the Aranui/Bexley paddocks to 5-9 geese/ha at Lake Kate Sheppard paddocks (Figure 3.4). In summer, both Aranui/Bexley and Lake Kate Sheppard paddocks had 5-9 geese/ha but only the Lake Kate Sheppard paddocks maintained this density throughout the whole year with the highest density at this site in winter (9.4/ha) (Figure 3.4).

Along the Avon/Ōtākaro River corridor geese were present at highest density during summer, ranging from 1-19 geese/ha from New Brighton through Burwood to Dallington/Wainoni, respectively (Figure 3.4). Many geese were observed on the river in December and January during the moult period with the majority situated in the Dallington/Wainoni segment (16.8/ha).

Seasonal variation in behaviour and time budgets

Foraging was on average the most frequently exhibited behaviour across all seasons (42.73%±0.02), followed by moving (20.07&±0.01) and then sitting (15.15%±0.01) (Figure 3.5). Foraging was observed most frequently in autumn (51%±0.03) and lowest in winter (36.29%±0.04). Between spring and summer there was a small but significant increase in foraging activity (Estimate = 0.112, SE = 0.043, t_{293} = 2.61, p = 0.047). From autumn to winter there was a significant decrease in foraging (Estimate = 0.147, SE = 0.047, t_{293} = 3.15, p = 0.01).

On average, preening was most frequent in summer (12.16%±0.02) and least in autumn (5.77%±0.01), which is expected due to the moult taking place in the summer (Figure 3.3). In concordance with the moult, there was a small significant decrease in preening from summer to autumn (Estimate = 0.064, SE = 0.025, t_{293} = 2.167, p = 0.046).

Sleeping was exhibited the most during winter (8.06%±0.2) and least during autumn (0.88%±0.05), which when foraging is considered could indicate that Canada geese are preparing for the winter by sleeping less and eating more frequently (Figure 3.5). There was a significant increase in sleeping activity from autumn to winter (Estimate = 0.072, SE = 0.02, t_{293} = 3.41, p = 0.004).

Sitting was on average more frequent during winter (21.24%±0.03) and least in summer (11.69%±0.01). Between autumn and winter there was a significant increase in sitting behaviour (Estimate = 0.09, SE = 0.03, t_{293} = 3.412, p = 0.004).

Vigilant behaviour was most frequently observed during spring when breeding was occurring (13.16%±0.01) and least during winter (5.77%±0.01) (Figure 3.5). From spring to summer there was a significant decrease in vigilant behaviour (Estimate = 0.07, SE = 0.02, t_{293} =

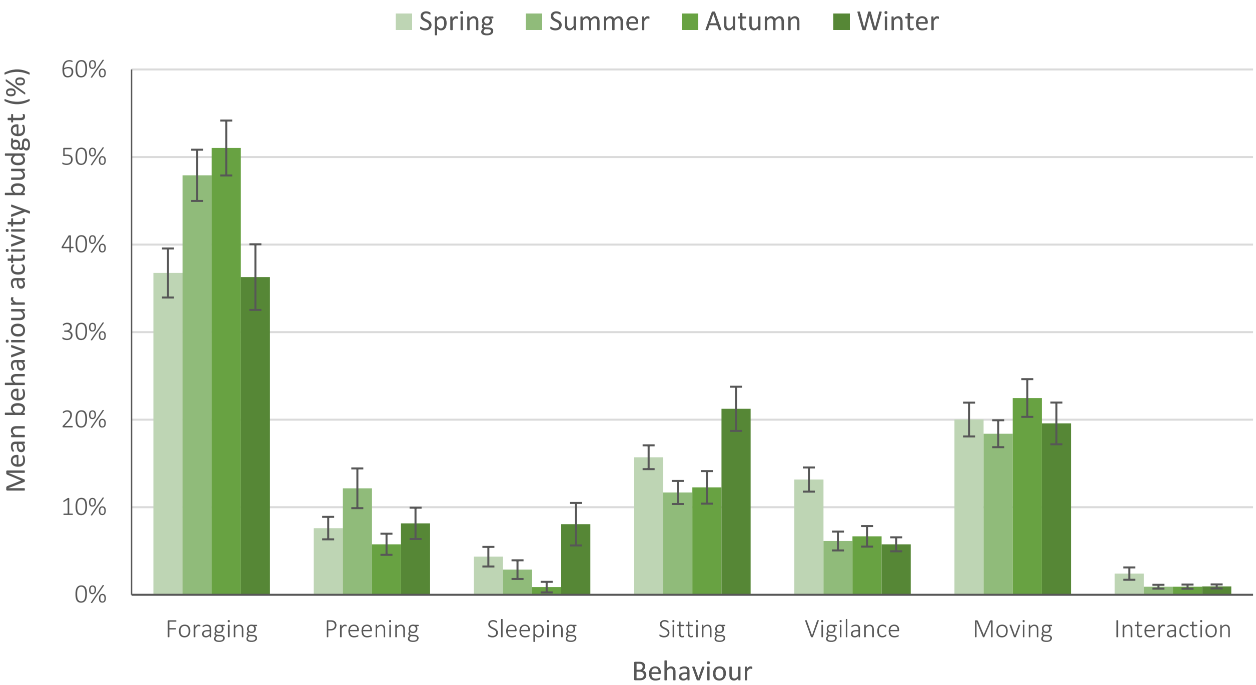

Figure 3.5. Seasonal differences (spring, summer, autumn and winter) in activity budgets for Canada geese across all sites visited in Christchurch City, 2019-2020. Standard error of the mean values are shown for each behaviour.

4.39, p < 0.001). There was also a significant increase in vigilance from winter to spring (Estimate = 0.074, SE = 0.02, t_{293} = 4.48, p < 0.001).

Canada geese moved most frequently on average during the autumn (22.48%±0.02) and least in summer (18.4%±0.02). Interactions among geese were more common during spring (2.42%±0.01), when birds are pairing for the breeding season. Interaction behaviour in the other three seasons was very similar. Moving and interaction behaviours were not significantly different between seasons.

Diurnal variation in population size

There was no significant difference in observed Canada geese numbers across morning, midday and afternoon phases throughout the study period (Kruskal-Wallis χ^2 = 2.5233, DF = 2, p = 0.2832) (Figure 3.6). The highest numbers of geese were observed during the midday phase (72.4%±7.23) and the lowest during morning (47.5%±7.8) (Figure 3.6).

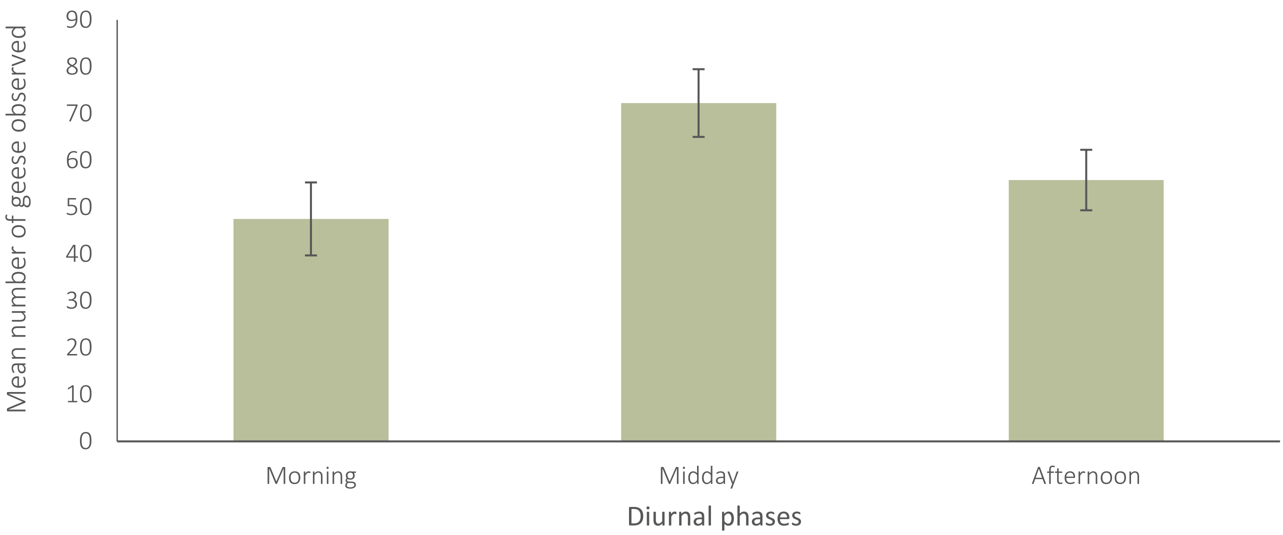

Figure 3.6. Diurnal variation of Canada goose numbers across all visited sites in Christchurch City from January 2019 to December 2019. Standard error of the mean values are shown for each diurnal phase.

Population size in relation to habitat and time of day

Highest mean number of geese observed was in red zone habitats during midday (120.3±15.5) and lowest in the morning on river sites (23.3±6.7) (Figure 3.7). There was a significant difference between the number of geese on lakes and red zone paddocks at midday (Estimate = 59.8, SE = 14.5, Z = 4.12, p = 0.001). Similarly, there was a significant difference between red rone paddocks and river sites at midday (Estimate = 66.68, SE = 17.9, Z = 3.73, p = 0.006) and also a small significance in the afternoon for the same sites (Estimate = 71.17, SE = 22.6, Z = 3.15, p = 0.044) (Figure 3.7).

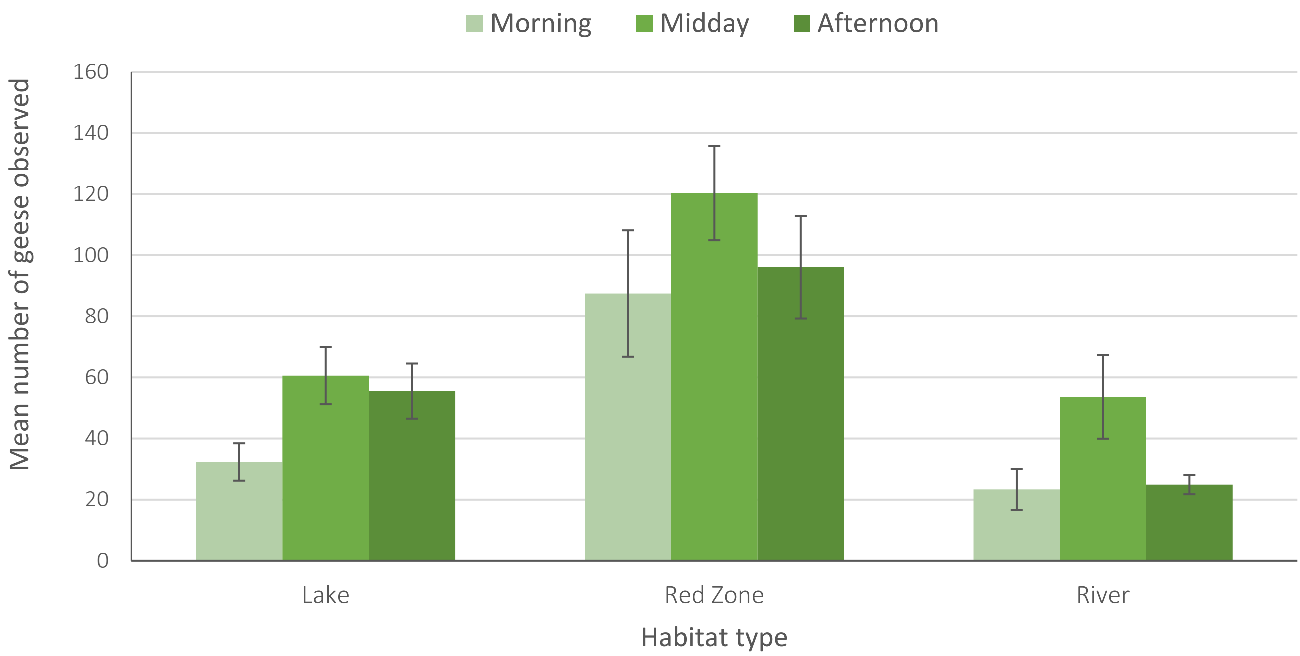

Figure 3.7. Diurnal variation in mean number of Canada geese across lake, red zone and river sites visited in Christchurch City, 2019-2020. Standard error of the mean values are shown for each habitat type.

Diurnal variation in behaviour and time budgets

Across the three diurnal phases there were no significant differences in preening, sleeping, sitting, vigilance, moving and interaction behaviours (all p <0.05). Between midday and afternoon there was a significant decrease in foraging in Canada geese (Estimate = 0.11, SE = 0.04, t_{294} = 2.98, p = 0.009) (Figure 3.8).

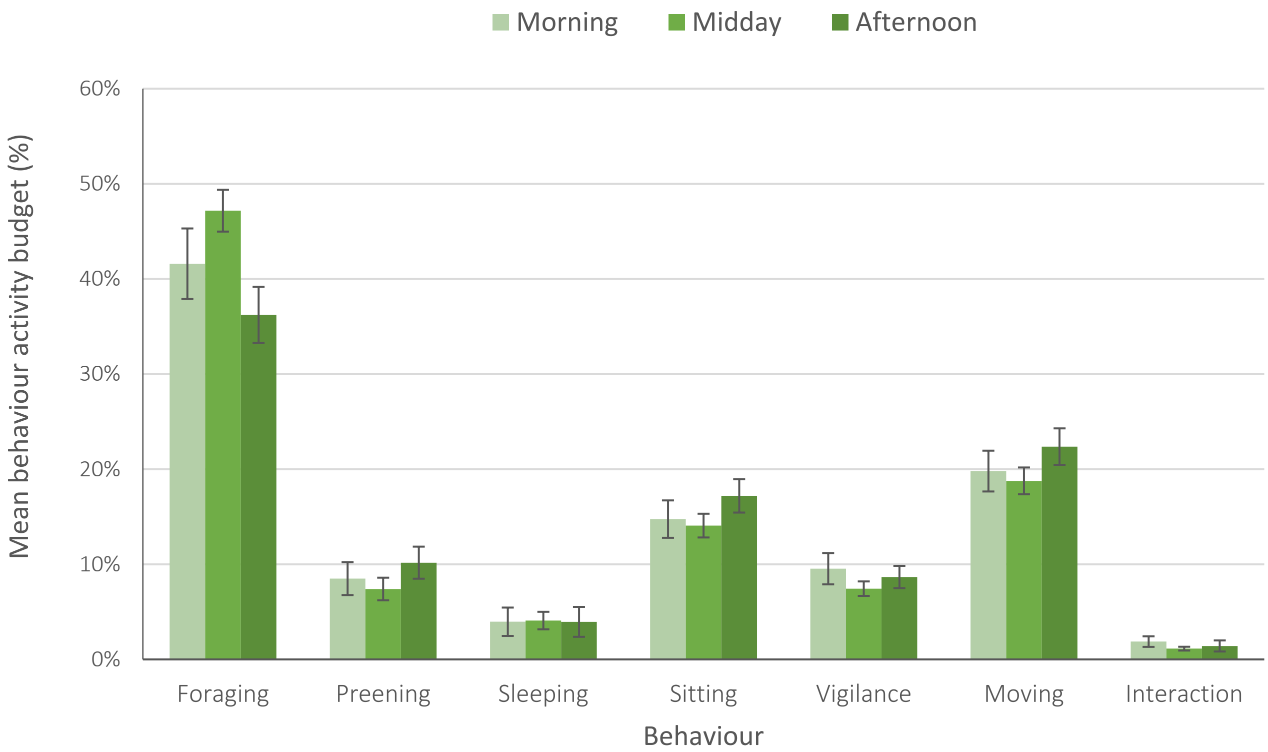

Figure 3.8. Diurnal differences (morning, midday and afternoon) in activity budgets for Canada geese across all sites visited in Christchurch City, 2019-2020. Standard error of the mean values are shown for each behaviour.

Variation in behaviour and time budgets in relation to habitat

On red zone paddocks, foraging was observed most frequently (68.6%±0.02), and >20% than other habitats on average (34.8%±0.02 and 34.2%±0.03 for lake and river sites, respectively) (Figure 3.9). Vigilant behaviours were also more common on paddocks (12.3%±0.01) than the other two habitats. Preening, sleeping, sitting, moving and interaction behaviours were exhibited least on the red zone paddocks (Figure 3.9). Geese observed on lake habitats exhibited preening (11.6%±0.01), sitting (18.3%±0.01) and interaction (1.7%±0.003) behaviours more frequently than on the other habitats. Sleeping (6.1%±0.02) and moving (29.5%±0.030) behaviours were most often observed on river sites (Figure 3.9).

Foraging was significantly more frequent on red zone paddocks than other habitats (Estimate = 0.34, SE = 0.04, t_{294} = 8.32, p < 0.001). Vigilance was also significantly more common on red zone sites (Estimate = 0.07, SE = 0.02, t_{294} = 3.99, p < 0.001). On red zone sites, preening

(Estimate = 0.06, SE = 0.02, t_{294} = 2.56, p = 0.011), sleeping (Estimate = 0.056, SE = 0.02, t_{294} = 2.609, p = 0.01), and sitting (Estimate = 0.088, SE = 0.03, t_{294} = 3.365, $p < 0.001$) were significantly less common than on lake and river sites (Figure 3.9).

There were no significant difference between lake and river habitats for all behaviours apart from moving. Movement was more frequently observed for Canada geese on rivers than lakes (Estimate = 0.08, SE = 0.02, t_{294} = 3.462, $p < 0.001$), and rivers than red zone paddocks (Estimate = 0.2, SE = 0.03, t_{294} = 7.327, p = 0.002). Additionally, movement was significantly more common on lakes than red zone paddocks (Estimate = 0.12, SE = 0.02, t_{294} = 5.33, $p < 0.001$) (Figure 3.9).

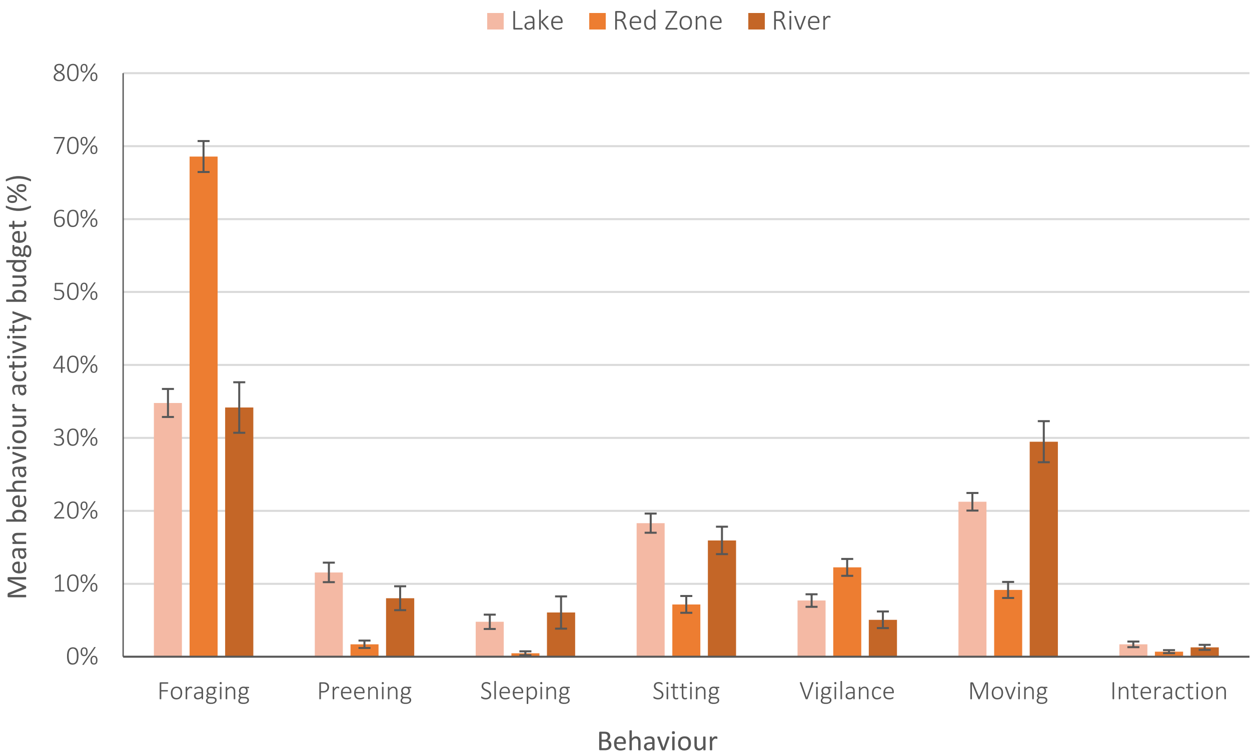

Figure 3.9. Habitat differences (lake, Red Zone and river) in activity budgets for Canada geese across all sites visited in Christchurch City, 2019-2020. Standard error of the mean values are shown for each behaviour.

3.3 Discussion

Canada geese were present within Christchurch city year-round. Among all study sites, Canada geese were most abundant in summer (93.58±7.9) and least during spring (25.49±5.5), however the peak mean was during winter in June (152.6±36.8) (Figure 3.1). The decrease in urban goose populations from winter to spring was expected as geese disperse from their winter roosting habitats to breeding grounds in the high-country (Imber 1971; Potts 1984; Potts and Andrews 1991; Win 2001). These dispersal behaviours appear to be a result of management strategies from the 1980's that shifted Canada geese away from colonial breeding (White 1986; Holloway et al. 1987).

When the breeding cycle was completed when there was a significant increase in geese returning to Christchurch in December. This migratory population may have consisted of non-breeders and failed breeders that came to the city to join the resident population to moult though not confirmed. Allan et al. (1995) suggested that earlier moult-migrants could be failed and non-breeders. This was most evident at Styx Mill Reserve where there was a considerable shift in density between spring and summer by geese returning to moult (1.9 to 52.2/ha, respectively) (Figure 3.3). This seasonal variation is also evident at Lake Kate Sheppard which is a winter roosting lake (79.1/ha), but also a site for some breeders and non-breeders in spring (15.2/ha) and a moulting lake in summer (52.5/ha) (Figure 3.4). Geese are known to roost with other geese that shared the same breeding grounds (Raveling 1979c) and they have a tendency to use the same wintering grounds as the previous year (White 1986). Thus, there should be many geese that have predictable behaviour, particularly those that are permanent residents.

Goose were most widespread and at highest density during the summer for both east and west study sites (Figures 3.3; 3.4). It is important to note that there was still considerable numbers of geese present during winter (Figure 3.1). This is similar to what Dorak et al. (2017) found with large urban goose populations in Chicago, that traded increased foraging opportunities outside of the metropolitan area for increased safety within an urban sanctuary.

As Canada geese are now classified as pest species in New Zealand, they can be shot all year-round with no limit. This presents quite a different challenge compared to countries where the species may be native and managed accordingly. In Chicago, more than 85% of the population remained resident and not a single goose was shot, while the other 15% were subjected to hunting pressures and therefore experienced reduced survivability (Dorak et al. 2017). Those remaining in Christchurch beside the red zone paddocks may have an advantage over those that venture to rural lakes and wetlands during the winter, but the movements of geese need to be studied further before any conclusions can be drawn about variation in survival in different habitats.

Mean numbers of geese were highest in red zone sites with no significant change throughout the year but peaking during winter (Figure 3.2). Foraging was the most common behaviour observed in the red zone paddocks (Figure 3.9) which provided a consistent presence of short-cut grass all year-round. This study found that foraging was habitat dependent, with 66.6% of an activity budget at red zone sites compared to only 34 and 35% at river and lake sites, respectively (Figure 3.9). Older studies have found that Canada geese in New Zealand exhibit similar foraging rates: 61-69% (Win 2001) and 70% (Potts and Andrews 1991) when grazing on agricultural sites. However, these papers did not compare behaviour across different habitats. My study found that within an urban environment most behaviours were bound to a specific habitat type; preening, sleeping, sitting and moving were mostly observed on lakes and rivers, while foraging and vigilance were most common on red zone paddocks (Figure 3.9). In addition, the behaviours also varied according to time of the year with foraging taking place more frequently in summer and autumn, preening in summer, sleeping and sitting in winter and vigilance in spring (Figure 3.5).

Increased thermoregulatory stress in winter may favour 'pre-bulking' in autumn as geese make preparations for a time requiring reduced energy outputs (Davis et al. 1989). Canada geese has adapted to a diet consisting of only domesticated grasses (Conover & Kania 1991).

With LINZ maintaining the red zone paddocks year-round there is a reliable supply of domestic grasses, particularly as old suburban land returns to wetlands. Geese only have a short flight (<1 km) from key lake and river habitats to reach these new foraging opportunities (Figure 3.4). Thus, in winter urban populations of geese likely expend little energy to reach foraging habitats compared to more rural populations. This may increase survivability compared to those that may winter in the alps or on larger lakes in Canterbury. Nevertheless, while sedentary behaviours (sleeping and sitting) were still most frequent in winter the numbers seen on red zone paddocks peaked in June, perhaps indicating that these large over-wintering flocks foraged together on the same paddocks. This is an interesting contrast with geese studied at Lake Grasmere in the Southern Alps that performed sedentary behaviours more on fields in the summer rather than lakes in winter as seen in Christchurch (Win 2001).

Geese numbers significantly rose during summer as many occupied the Dallington/Wainoni stretch of the river to moult in December and January (Figure 3.2; Figure 3.4), supported by the increase in preening behaviours observed in summer (Figure 3.5). Lake Kate Sheppard, Styx Mill and this stretch of river had the highest numbers of geese during the moult, with between 130 and 300 individuals at any given time.

Diurnally, goose numbers were consistent throughout all sites and with little change to behaviours from morning to afternoon. Foraging did decrease between midday and afternoon hours, perhaps indicating a rest period as sitting and preening behaviours increased slightly at the same time (Figure 3.8). Due to the red zone paddocks' proximity to inhabited suburbs there were quite often dog walkers that would disturb the grazing geese. Though not recorded systematically, the afternoon hours appeared to be when people are more likely to perform recreational activities in these sites and this could account for variation in goose presence here. Win (2001) observed similar variations in foraging and goose presence on fields due to the disturbance of farming activities. Regardless, it may also be the case that nutritional requirements are met within the afternoon hours and so geese return to sites where they are more likely to perform sedentary behaviours. Gauthier et al. (1998) observed a shift from foraging to sedentary behaviours as the day progressed and nutritional needs were met.

3.4 Conclusions

Goose presence peaked during both the summer, when birds came to the area to moult, and again in winter, as birds spent the non-breeding season in the area. Large numbers of geese migrated away from the city for the breeding season in August and September but returned for the annual moult in December. Most of these moulting birds were situated at Lake Kate Sheppard, Styx Mill Reserve and on the Dallington/Wainoni stretch of the Avon/Ōtākaro River. Foraging was the most commonly observed behaviour across all diurnal/seasonal phases and among habitats in this investigation. Behaviours showed to be predominantly dependent on habitat type with grassy paddocks in the red zone providing a key foraging site for Canada geese while lake and river sites were used for sleeping and preening. Foraging on lake and river sites was more common in spring and summer when water temperatures rose, and the vegetation levels increased. Geese foraged most in autumn as they prepared for the winter and this was significantly higher than in spring and winter. With the influx of geese for the annual moult in the summer and the high frequency of foraging on the red zone paddocks, considerable attention is needed to ascertain how the future of the red zone paddocks may influence populations of Canada geese. Should the red zone become more heavily planted in native forest or any other recreational type of land use, the movements of Canada geese may likely shift to accommodate any loss in suitable foraging habitat.

Expectations of Canada geese movements in the past were based on seasonal variations in behaviour as they moved to find suitable foraging (Raveling 1979c; McWilliams and Raveling 1998), targeting higher yield agricultural lands during autumn and winter in particular (Owen 1980). This would therefore have drawn concerns as to how many geese were flying out of the city and past the airport to forage on the Canterbury Plains. However, this investigation found no geese were visiting agricultural sites near to the airport at any time in the year. Thus, if plans to re-forest the red zone go ahead then it could be expected that Canada geese may need to find food elsewhere, and this might involve movements on the plains or fields closest to the city. In the next chapter, the movements and home-ranges of three populations of Canada geese are observed to help address how an urban population may differ from a non-urban and to also investigate how the movements of an urban population may present hazards to an International Airport.

CHAPTER 4

SPATIAL TRENDS AND MOVEMENTS OF CANADA GEESE IN CHRISTCHURCH AND CENTRAL CANTERBURY, NEW ZEALAND.

4.0 Introduction

Historical Risk

By 2002 the civil aviation industry fronted costs that exceeded US$1.2 billion annually that were related to wildlife-aircraft strikes and birds were most frequently related to damages (Allan 2002). Between 1990 and 2003, 97% of more than 50,000 collisions with wildlife involved birds which were reported to the Federal Aviation Administration (FAA) in the USA (Blackwell & Wright 2006). More recently, 11,315 strikes were reported to the FAA in 2013 that for direct and indirect damages costed approximately US$937 million (Dolbeer, Seubert and Begier 2014).

It is clear that airstrikes with wildlife in the vicinity of runways, take-offs and landings present dangers to the crews, passengers and any ground structures particularly involving waterfowl (Anatidae) that fly >152.4 m above ground level (AGL) (Dolbeer 2006). Previous to 2013, strikes in the range ≤152.4 m AGL within airport boundaries (historically 74% occurred in this range) had declined during a period of successful management strategies (Dolbeer et al. 2014). Nevertheless, during this time the frequency of significant collisions above 152.4 m AGL steadily increased (Dolbeer et al. 2014). Concerningly, for the first time since 1990 when the FAA National Wildlife Strike Database began, more wildlife strikes with commercial crafts occurred outside airport properties (n = 141) than inside (n = 118) (Dolbeer et al. 2014). Further, Dolbeer et al. (2018) reported Canada geese as the 2nd highest risk to the FAA between 2010 and 2015 with 121 damaging strikes of 232 total strikes accumulating a cost of US$10,872,559. Strikes occurring in the range >152.4 m AGL and outside of airport properties present complex risks due to limited mitigation strategies available for these occurrences. The

Civil Aviation Authority (CAA) stated that bird strikes occurred most frequently below 609 m AGL (2000 ft) (CAA 2002), that for aircraft on standard approaches relates to an approximate radius of 13km from the runways where this altitude is reached (Baxter and Robinson 2007). Additionally, airports operating both piston- and turbine-powered engines (as does the Christchurch International Airport (CIA)), consider 1.5 km to 3 km respectively, to be priority zones for wildlife management. This is due to planes generally reaching ≤152.4 m AGL at 3 km from a runway (Flight Safety Foundation 2000). This is particularly relevant for the CIA due to the dozens of urban lakes and wetland habitats within 5km of the property boundaries.

Canada geese are a large flocking species with an average adult weight of >3.6 kg. This exceeds a vast majority of civil aircraft engine tolerances during an impact. Considerably lowering an engines capacity to keep working (Eschenfelder 2000; Dolbeer & Eschenfelder 2003). Of all Canada goose strikes, 67% resulted in damage to aircraft (Allan 2006), and with shifts from migratory to residential behaviours (Dolbeer et al. 2014), populations of Canada geese in urban areas are thus increasing. Therefore, presenting an expanding list of hazards to aviation authorities worldwide. As noted by Dolbeer et al. (2014) residential populations of Canada geese increased 3.5-fold from 1.1 million to 3.8 million in the USA between 1990 and 2012, reinforcing concerns to civil aviation industries. Particularly noteworthy when goose flocking behaviour, size, year-round presence and attraction to open spaces are considered. The former three are influenced by keen behavioural plasticity exhibited by Canada geese (Dorak et al. 2017).

Migratory and Resident geese in Canterbury

Canada goose populations steadily increased throughout New Zealand following their introduction in the South Island at the beginning of the 20th century. From <50 individuals, approximately 40,000 reside in the South Island (Heather & Robertson 1996), despite many population culls through the 1980s that resulted in >30,000 adult goose deaths during the period (Holloway et al. 1997). In counter to culls of breeding/moulting colonies across the east coast of the South Island, Canada geese have shown adaptive changes in behaviour and have begun dispersing to isolated valleys and tributaries within the Southern Alps to breed (White 1986). As a consequence, there are now synchronous movements of geese between coastal lakes and lagoons to the mountains during the spring and a return flight at the beginning of summer for the annual moult. Further, expansion of wetland habitats including the red zone in Christchurch, have resulted in growing optimal space for Canada geese within urban environments. Similarly, in Chicago 85% of Canada geese remained on urban lakes during winter, disregarding migratory behaviours and this increased their survivability compared to the 15% that migrated south (Dorak et al. 2017).

The increasing presence of Canada geese in Christchurch City and the synchronous flights between coastal lagoons and lakes to the mountains across the Canterbury Plains pose worthy concerns to civil aviation in the future. With average numbers of geese in Christchurch between 2000-3000 individuals, and ~1000 permanent residents (Crossland 2018, unpublished), there are sufficient numbers departing the urban environment to warrant a spatial investigation into their movements. Further, to see if individuals are flying to and from the numerous urban lakes within the 3-5 km vicinity of the airport runways as year-round residents or if the number leaving the city is more likely than predicted.

Aims

Utilising GPS tracking technologies would enable the collection of highly detailed information on Canada goose behaviour and differences in population trends throughout the wider Christchurch region. The aim of this study was to fit GPS-collars to geese across three locations where populations were widely separated; Lake Ellesmere/Te Waihora south of Christchurch City, Lake Grasmere in the Southern Alps, and an urban population within Christchurch City itself.

Telemetry data from individuals in these three populations would collect data for the year 2019 and further that could determine the varied interactions across landscapes and also what populations may be connected among the wider Canterbury region. This provides greater detail than leg- or neck-banding individuals; flight speeds, altitudes, flight times and lengths, size of home ranges and frequency of movements are key exhibitions that will assist in better understanding the current Canada goose populations around Christchurch. Specifically, pinpointing which populations of geese tend to exhibit more activity during the year and how. By establishing the spatial patterns of Canada goose movements and distributions across the year, the Christchurch International Airport could have more detailed information in which to better plan future operations that concern wildlife strikes. This study would also aim to show that installing GPS-collars on Canada geese is a viable option for future population investigations to assist species management strategies.

4.1 Methods

The procedures for capturing and fitting Canada geese at Lake Kate Sheppard (43°29'58.2"S 172°42'07.3"E) in Christchurch City are outlined in the Chapter 2 methods which involved the attachment of 4 GPS-collars and 66 leg-bands to individuals. Furthermore, the specifications for the type, brand and dimensions of the GPS-collars are described in Chapter 2 methods also. In addition to the city birds being manipulated, 3 birds at Lake Ellesmere/Te Waihora (43.7928° S, 172.4969° E) and 3 birds at Lake Grasmere (43.0616° S, 171.7746° E) were tagged with GPS-collars. The sizes of both lakes were considerable compared to Lake Kate Sheppard and thus required different approaches for capture on each lake respectively.

Lake Ellesmere/Te Waihora

Mud flats on the northern shore of Kaitorete Spit (GPS coordinates) were chosen to herd the moulting geese where they come ashore to forage on the grassy verge. A group of volunteers and myself attempted to herd a small flock of geese to the end of a muddy bay by cutting them off from the lake edge. Due to the nervous nature of the moulting geese it become clear that herding them against the verge was improbable. Geese hiding in the grass had spooked themselves and began to flap across the mudflat and hid themselves in the tall grass and shrubs. Volunteers were able to use nets and towels to capture the birds as they remained stationary and quiet in the grass attempting to avoid our attention. A handful of geese were leg-banded and 3 of the geese were fitted with the GPS-collars and released back towards the lake.

Lake Grasmere

On the western shore of the lake there was suitable foraging for moulting geese in amongst some shrubs, evidence of geese walking through this area was present. Only three volunteers including myself were present for capturing geese and two of us used kayaks to access the water. Fog in the early morning allowed us to approach the geese quietly and we were able to herd individuals against the shore until they hopped off the water. I would attempt to get out of the kayak and net the bird before it became startled and flapped back across the water. We were successful in capturing 3 geese to fit the GPS-collars onto.

At the time of capture there was no cellular network within the Cass Valley in the Southern Alps. It was expected that throughout the year that geese would disperse during the winter and return to the coastal lagoons and lakes. The cellular network extends to several of the valleys to the south and east of Lake Grasmere however it can be unpredictable due to the extreme terrain.

GPS-collar data-collection parameters

Druid Technology™ (https://www.druid.tech/; see Chapter 2 for specifications), provide a website profile where one can manage the devices and track them in near real-time. The website enabled us to fine-tune data collection parameters to ensure devices had suitable battery life and to also improve the locating of birds for behavioural observations. The standard collection regime was a GPS location every 1 hr period and environmental data (ENV) every 1 hr (ambient temperature, air pressure, light-intensity). Behavioural data (BHV) could be collected every 10 or 30 minutes however, if the individual increases activity such as taking flight, the rate of BHV collection increases to every 20 seconds. The rate increase is determined by the effect the individual would have on the internal three-axis accelerometer.

Communication rate for the devices is based off of the cellular network, Global System for Mobile communications (GSM), and can range between 5 minutes and 7 days. This determines how often the device will receive/transceive information to and from the company servers. The standard rate of communication during this study was 8hrs, though this was changed regularly dependent on the battery life of devices. Druid Technology™ also provide an application to use on a smartphone that enables the same customisation of device parameters. When bad weather was expected, it became routine procedure to slow data collection and communication rates to reduce the amount of battery lost during low-sunlight hours. With the creation of geofences on their website the observer is able to receive notifications when GPS-collared individuals have crossed specific boundaries. This provides highly detailed and current awareness of goose activities.

Data Management

Movebank (Wikelski & Kays 2020) is an online data repository for researchers to share, analyse and archive telemetry data related to animal movements. Movebank was used in this study to manage and store all telemetry data from the Druid Technology™ servers via a cooperative streaming service that connects the devices to Movebank and allows all data collected to be automatically categorised and archived. Once archived, data was downloaded in monthly periods starting with January 15th, 2019 for each active tagged animal from each of the three populations. The start of the monthly period was following at least a single whole week from manipulation to provide some habituation time for the animal. The monthly segments produced more manageable data chunks that could be further filtered to sort desired lists of diurnal activity, altitudes and velocity for analyses.

Data Analyses

Monthly data chunks were analysed in R-studio (RStudio Team 2008) using the *adehabitat package* (version 0.4.18) (Calenge 2009). Adehabitat is a tool to analyse space and habitat use for tagged animals including the mean convex polygons (MCPs) illustrating a home range in units of hectares. Monthly data chunks analysed with 90% MCPs were used to compare changes in home range distribution and size between the three populations of tagged animals in this study. Seasonal and overall comparisons were also produced using the same methods. Mean home ranges were plotted in two population groups to illustrate monthly variations. Home range was plotted on a logarithmic scale to accommodate major changes.

Mean flight altitudes (≥0.5 m and <250 m ASL) for each bird and population (Christchurch, Ellesmere and Grasmere) were compared across monthly and diurnal phases (24 hrs). Velocities (≥ 0.5 m/s) were assessed in the same manner. Both altitude and velocity was filtered in this manner to remove data where geese were not likely to be flying. Velocity (≥1 m/s) was also plotted against altitude (0-300 m ASL) for each season to further illustrate variation in Canada goose activity.

Maximum distances between locational fixes that were furthest from one another within a given month were measured using google maps and the Movebank.org data editor. These distances were then plotted as Christchurch birds and then Lake Ellesmere/Te Waihora and Grasmere birds.

Trajectory Presentations

Birds 3519 and 3594 from Lake Ellesmere/Te Waihora and Christchurch city respectively were compared using six trajectory images each. This was to show a clear illustration of how they varied in movements throughout the year. They also showed how it is possible for the two populations to be connected and what times of the year movements are most common.

4.3 Results

A total of 356,892 locational fixes were recorded from 8 of 10 Canada geese fitted with GSM/GPS collars. Two birds from Lake Grasmere never entered the radius of a cellular communication tower and so were unable to transmit their data. We can be confident of three possibilities; that they have died naturally, been shot by a hunter or are permanent residents within the Southern Alps. It has been observed in the past that permanent residents do reside at Lake Grasmere (Win 2001).

The furthest distance travelled by a tagged individual was 128.8 km by goose 3519 (Figure 4.3). Fitted at Lake Ellesmere/Te Waihora it also had the largest average home range at 226,473 ha over the 12-month period it communicated (Table 4.1). For Christchurch city birds, the furthest travelled was 26.3 km by goose 3594 (Figure 4.2) that also had the largest home range at 2,401 ha (Figure 4.1). Three other city birds never flew further than 4 km from where they were tagged and only ranged between 84-471 ha (Table 4.1). The only bird from Lake Grasmere (device 3509) appeared on the coast north of Christchurch in September and moulted in the city in December at a distance of 89.2 km away from its tagging location. From recorded data bird 3509's furthest distance travelled was 43.9 km (Figure 4.3). It had the third largest home range size at 8652 ha (Table 4.1; Figure 4.1) however, the device failed to store the data collected while it resided in the Alps between January to September 2019.

At Lake Ellesmere/Te Waihora, bird 3519 was the only goose to survive the whole year. Bird 3634 was shot by a hunter in March and the device was recovered and bird 3554 stopped transmitting in March and no device or bird were relocated (Table 4.1). Bird 3594 in Christchurch city communicated up until December 2019 and has since stopped. Birds 3555 and 3556 both stopped transmitting in October during the breeding season with concerns about battery power and their solar charging abilities. Bird 3556 was located at Lake Kate Sheppard in January 2020 and the device appeared to be damaged suggesting a device failure. Limited data on bird 3509 from Grasmere could

Table 4.1. Contains all Canada geese fitted with a GSM/GPS collar. Location tagged; E = Lake Ellesmere/Te Waihora, C = Christchurch City, G = Lake Grasmere. For each bird the period of successful device communication, average home range (ha) and furthest distance travelled (km) from site of manipulation are shown.

Goose ID	Location tagged	Communication period (months)	Average Home Range (ha)	Furthest distance away (km)
3519	E	12	226473	128.8
3634	E	2	6051	5.7
3554	E	3	12323	17.7
3555	C	10	84	1.4
3556	C	10	471	3.8
3594	C	12	2401	26.3
3801	C	6	221	2.96
3509	G	4	8652	89.2
3573	G	0	-	-
3686	G	0	-	-

be explained by the device becoming inactive until it reached cellular communication or that the data had been overwritten due to storage reaching capacity when unable to transmit to the servers.

Home ranges for birds in Christchurch fluctuated between 174 and 500 ha from January to July and Ellesmere and Grasmere birds ranged from 1000 to 13,000 ha respectively (Figure 4.1). Home ranges for Ellesmere birds slumped in July at the end of winter before dispersing in the breeding season (Figure 4.1). Ellesmere birds show considerably larger home range sizes than Christchurch birds where both show a peak in spring before the breeding season, 243,917 ha and 2401 ha for each population respectively (Table 4.1; Figure 4.1). Ellesmere and Grasmere birds peak in November at 1,039,168 ha when they return to the coast for the moult and spend time flying around Canterbury before settling. While moulting in December and January, all birds showed reduced home range sizes (Figure 4.1).

Seasonal Variation: Altitude and Velocity

From January to August the mean altitudes of tagged Canada geese remained between 5 and 8 m ASL (Figure 4.4). A small rise in the mean velocity in the Autumn to 3.2 m/s then decreased over winter to 1.3 m/s in July. Altitude throughout the winter remained around 8 m ASL suggesting a possible behaviour routine by Canada geese (Figure 4.4). August and September data suggested there was a restlessness among the birds, perhaps a Zugunruhe as several birds took exploratory flights around the Canterbury plains; birds 3519 and 3594 (Figures 4.7 and 4.8 respectively). Mean velocity peaked in September at 7.8 m/s and altitude at 18.6m ASL (Figure 4.4) and this is the period of time when goose populations had decreased rapidly in Christchurch as birds began pairing up and dispersing for the breeding season (see Chapter 3). Bird 3519 from Lake Ellesmere/Te Waihora performed a lot of flying in this time and spent the breeding season in the Poulter Valley in Arthurs Pass, Southern Alps (Figure 4.7, fifth inset image). Activity of geese decreased rapidly following the dispersal in spring with drops in mean altitude to 4m ASL and velocity to 1.8m/s in November (Figure 4.4).

The moult migration for non-breeders and failed breeders took place in November and December with a major increase in mean velocity and altitude (Figure 4.4). Only four birds were transmitting through this period with two in Christchurch and the remaining two birds from Lake Grasmere and Lake Ellesmere/Te Waihora. The latter two had both descended from the Southern Alps in this period performing a lot of flying compared with the two city birds that had not (Figure 4.3; Figure 4.7). Telemetry data suggested increased activity from geese arriving from the Southern Alps in November and December that was supported by rising population observations in Chapter 3 of this investigation.

The steepest relationship between altitude and velocity was recorded in spring followed by summer (Figure 4.6). Autumn and winter were similar in their lack of high altitude flying though there were still numerous recordings of flights faster than 5 m/s (Figure 4.6). Low altitude flights (<50 m ASL) in summer, autumn and winter may coincide with brief "pond-to-pond" and foraging flights. In the city large amounts of Canada geese were observed foraging in red zone habitats during these periods which are within 1 km of popular roosting sites (see Chapter 3).

Diurnal Variation: Altitude and Velocity

Figure 4.5 shows two distinct increases in mean altitude, at 08:00 am it peaked at 16.1 m and at 18:00 pm it rose to 11.7m. There were also two distinct increases in mean velocity, at 06:00 am it was 3.7 m/s and 18:00 pm it peaked at 4.4 m/s (Figure 4.5). Between the hours of 12:00 pm and 15:00 pm there were drops in both mean altitude and velocity indicating a period of less activity by Canada geese, a similar period of lessened activity occurs between 24:00 am and 04:00 am (Figure 4.5).

Tracking Data: Comparing Bird 3519 and 3594

Bird 3519 at Lake Ellesmere/Te Waihora had sites of preferential residence throughout the year. From January to April it inhabited Kaitorete Spit and the southern lakeshore. It then moved to the north east side of the lake for a period in May and June before flying across the lake north and south several times (Figure 4.7). Between July and August 3519 spent most of its time on the lakeshore at the east end of the lake. In September when birds became restless, 3519 took exploratory flights west along the Rakaia River corridor towards the Southern Alps (62 km distance from Ellesmere) before returning to Lake Ellesmere/Te Waihora (Figure 4.7). Following these flights, 3519 set off towards Christchurch and flew right past the International Airport at approximately 130 m ASL and at 20 m/s showing clearly that there is a connection between Canada geese in the city and those from Te Waihora. Landing in Kaiapoi township for a short period 42km away from Ellesmere. Bird 3519 then continued its journey to its breeding grounds in the Southern Alps at Poulter Valley (101.6 km from Ellesmere) along the Waimakariri River corridor (Figure 4.7). In November bird 3519 returned to Lake Ellesmere/Te Waihora but before settling for the moult it took another long flight to the west and south towards Rangitata Island (89.8 km from Ellesmere) and then north into the Southern Alps again, reaching its furthest distance away from the site of manipulation at 128.8km (Figure 4.7; Table 4.1). Bird 3519 returned and spent the moult at Lake Ellesmere/Te Waihora during December at the same site where it was tagged on Kaitorete Spit on the southern lakeshore.

In comparison to bird 3519, bird 3594 from the Christchurch population was much less far reaching. 3594 spent the majority of its time within 3km of the tagging site at Lake Kate Sheppard (Figure 4.8, first inset image). Much of 3594's time was spent between the Avon/ Ōtākaro River corridor and the Bexley and Lake Kate Sheppard red zone sites (See Chapter 3). Between August and September however, bird 3594 performed a series of flights to the south west headed towards the township of Lincoln (23.5 km from Lake Kate Sheppard) and then north to the township of Kaiapoi (13.5 km from Lake Kate Sheppard) (Figure 4.8, inset image 4 and 5 respectively). There were three flights south, each one longer than the previous and then the single flight north, before returning to the same sites as previous for the remainder of the spring and summer. The flights north and south indicate that there are likely shared networks between several populations as bird 3519 and 3594 both visited the same sites in Kaiapoi and flew past Lincoln.

Locational Fix Density

Figure 4.7 shows the density of all locational fixes recorded by the GPS/GSM devices fitted to Canada geese in this investigation. The three geese at Lake Ellesmere/Te Waihora show that they spent the majority of their time on the southern, northern and eastern lakeshores with only bird 3519 leaving the lake and spending >1000 fixes north at the Poulter Valley in the Southern Alps (Figure 4.9 a)). Goose 3509 from Lake Grasmere shows that it collected >1000 fixes in the foothills of the alps and on the Okuku River north of Christchurch (Figure 4.9 b)). 3509 also collected >1000 fixes at lakes in Pegasus township before moulting on the Avon/ Ōtākaro River in central Christchurch and collecting >1000 fixes. The Christchurch population of 4 birds collected >1000 across multiple zones of the Avon/ Ōtākaro River corridor and also the red zone paddocks within central Christchurch (Figure 4.9 c)). Only a single bird, 3594, from this population flew outside of the city but never collected >10 fixes in another location.

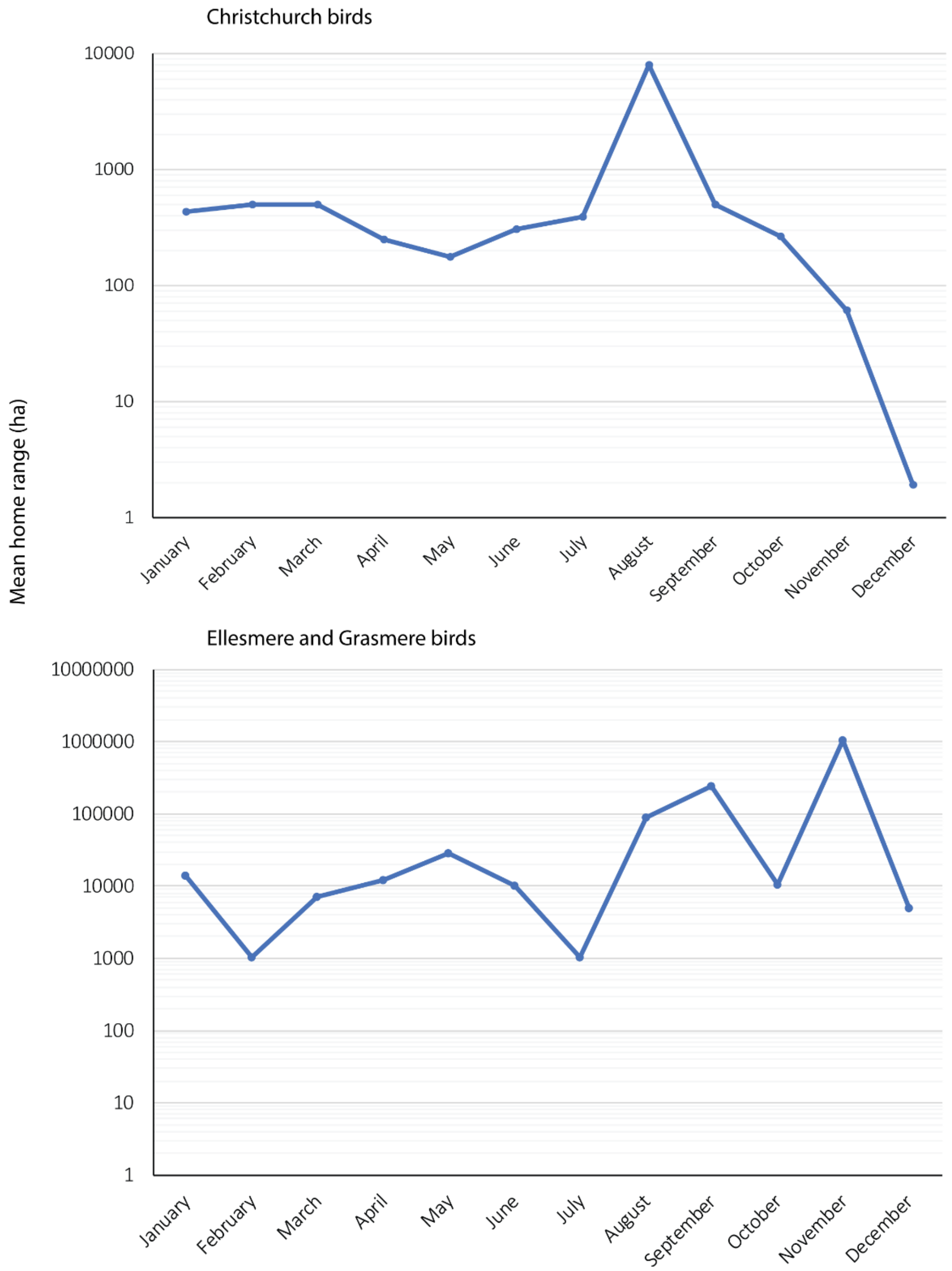

Figure 4.1. Mean home range (ha) is shown for all tagged birds in two groups across each month of the year 2019. The single Lake Grasmere bird is grouped with Ellesmere/Te Waihora birds (September to December). Mean home range is shown on a logarithmic scale to accommodate major shifts in range.

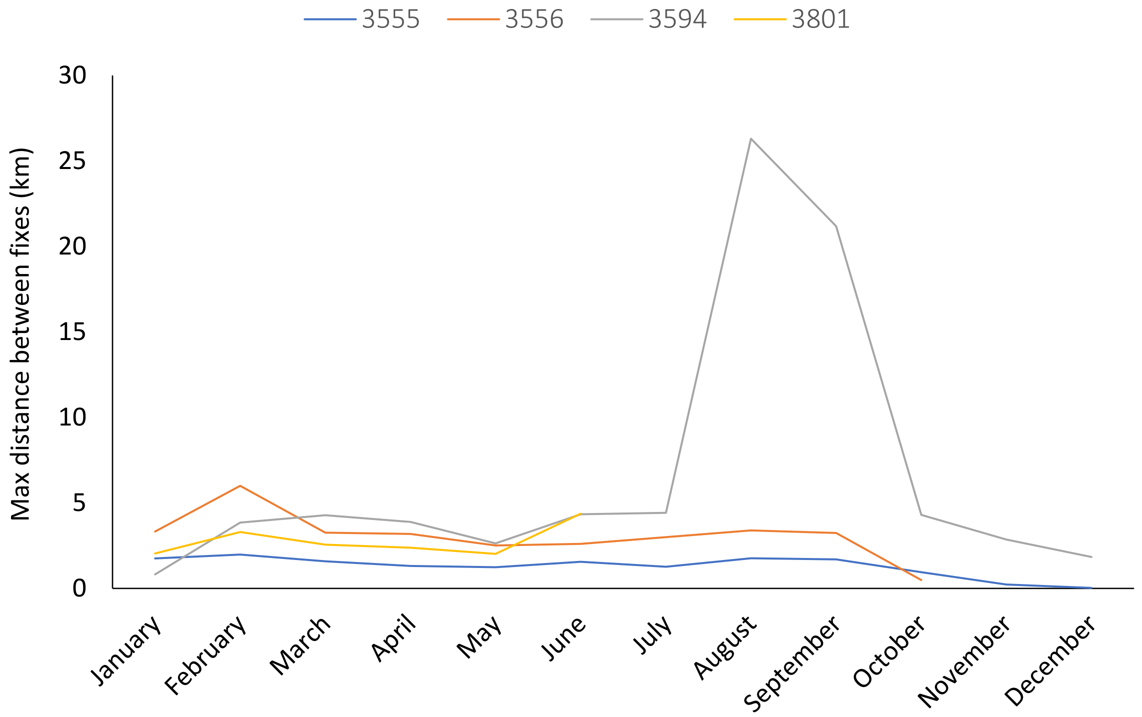

Figure 4.2. Max distance between furthest locational fixes from each monthly period for each bird fitted with a tracking device. Birds from the Christchurch city population are shown (n = 4).

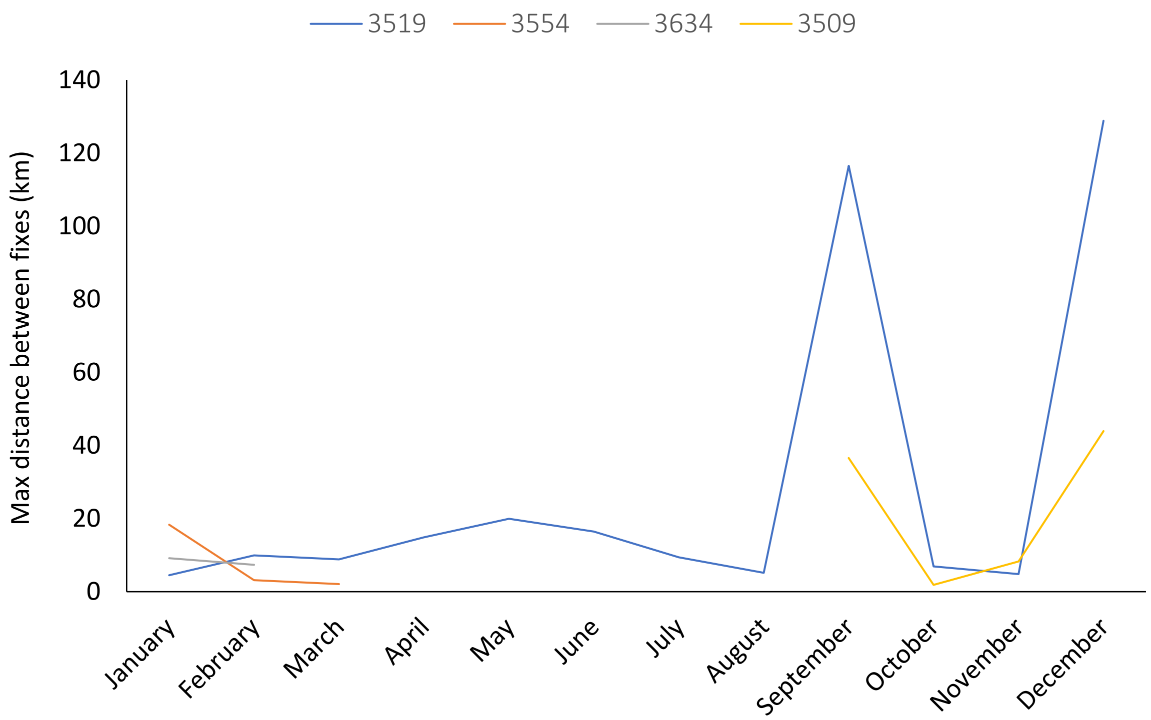

Figure 4.3. Max distance between furthest locational fixes from each monthly period for each bird fitted with a tracking device. Birds from the Lake Ellesmere/Te Waihora and Lake Grasmere populations are shown (n = 4).

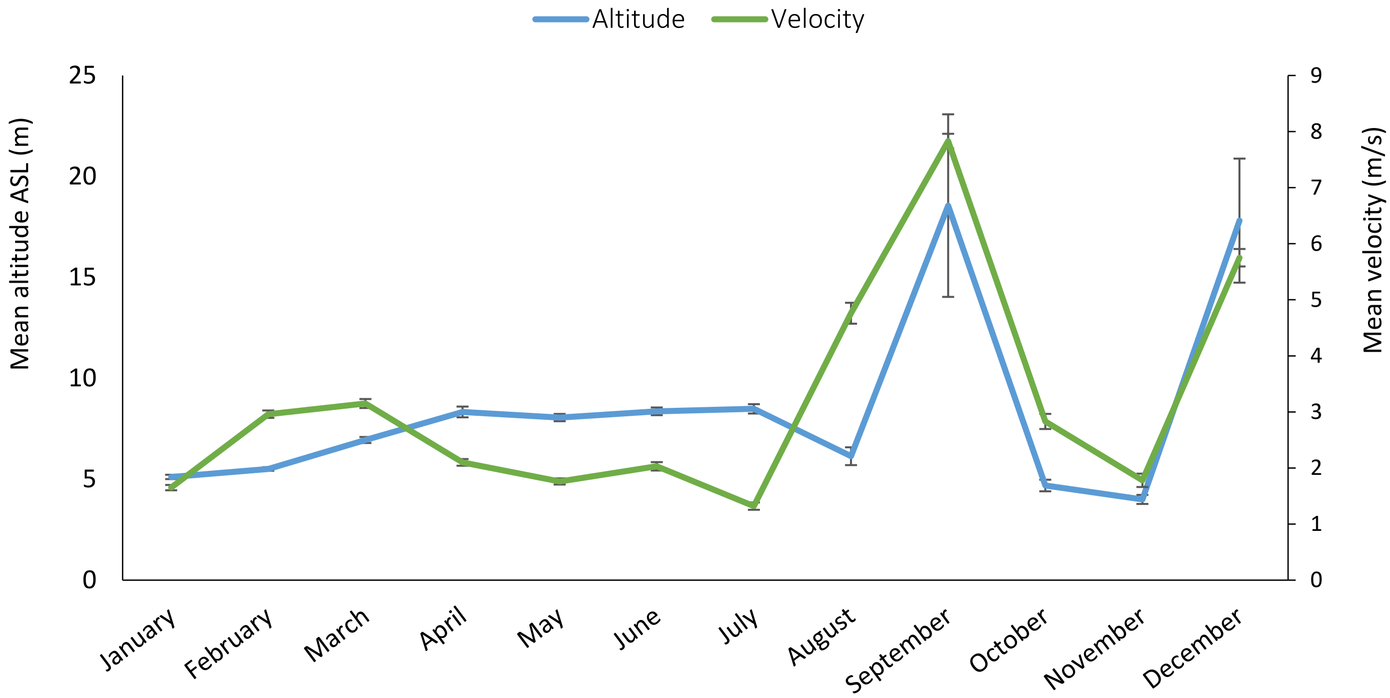

Figure 4.4. Seasonal variation in the mean altitude (m) and velocity (m/s) flown by GPS-tagged Canada geese, data greater than or equal to 0.5m and less than 250m ASL are shown.

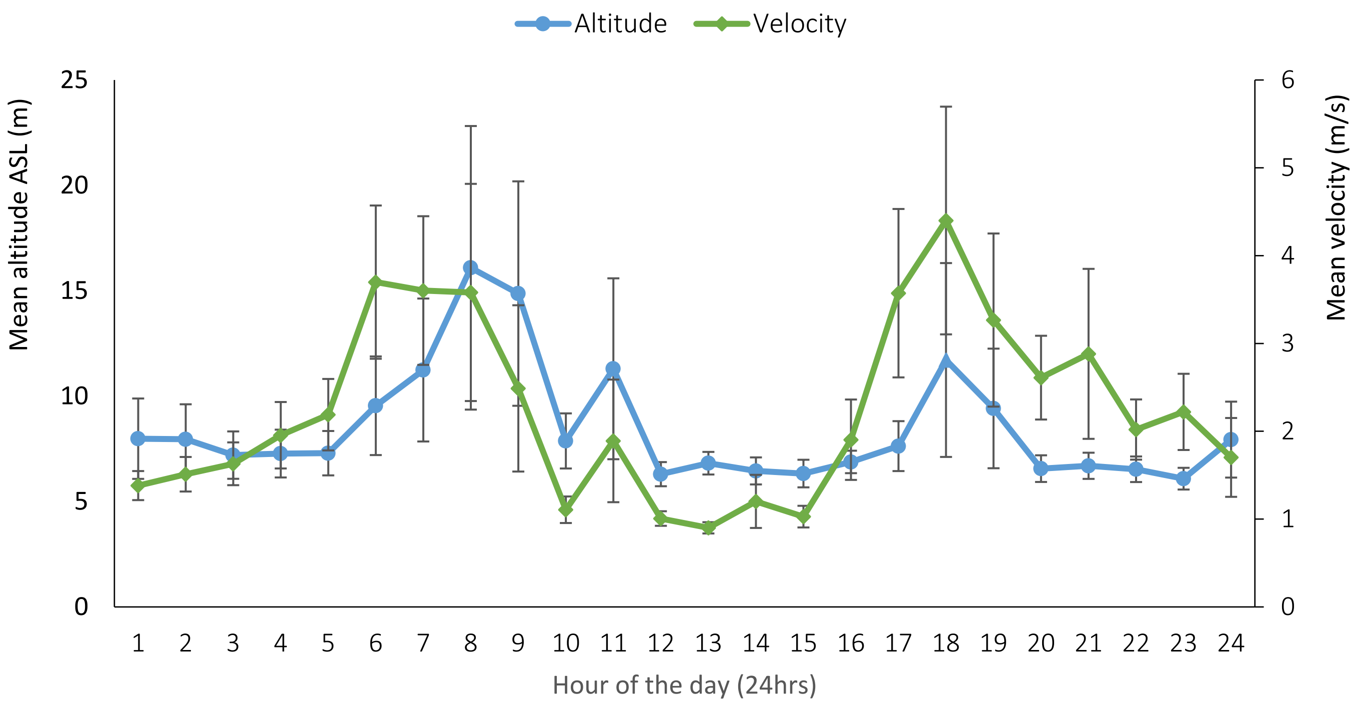

Figure 4.5. Diurnal variation in the mean velocity (m/s) and mean altitude (m) flown by Canada geese. Data greater than or equal to 0.5m/s are shown for velocity and between 0.5 and 250m altitude above sea level (ASL).

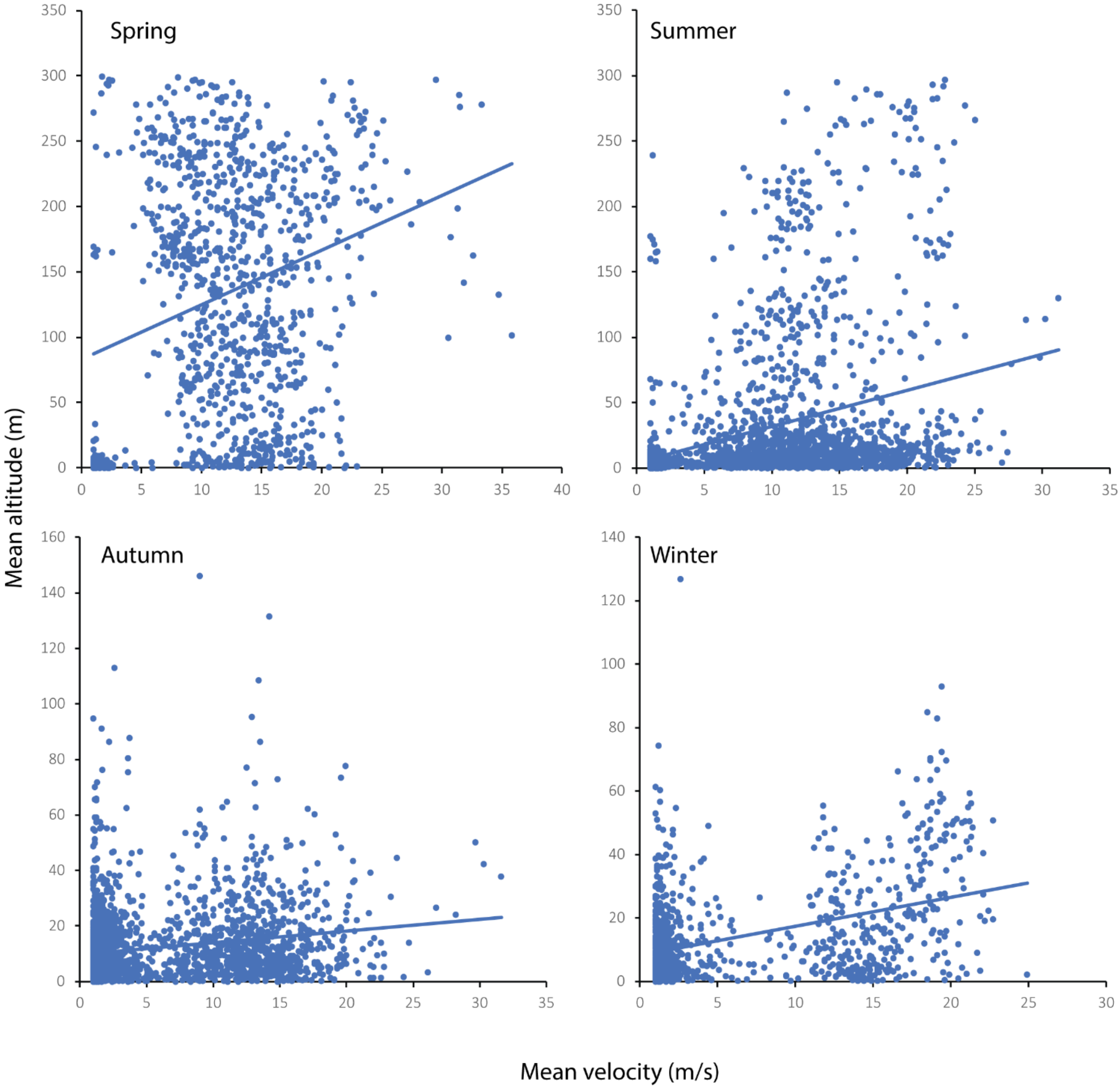

Figure 4.6. Mean velocity (m/s) plotted against mean altitude ASL (m) for each seasonal period. Altitude data between 0 and 300m ASL and velocities above 1m/s are shown. Trendlines show linear change in relationships. Spring (n = 1321) (y = 4.182x + 83.106), summer (n = 1968) (y = 2.749x + 4.3911), autumn (n = 2389) (y = 0.4227x + 9.6924), winter (n = 997) (y = 0.9043x + 8.3742).

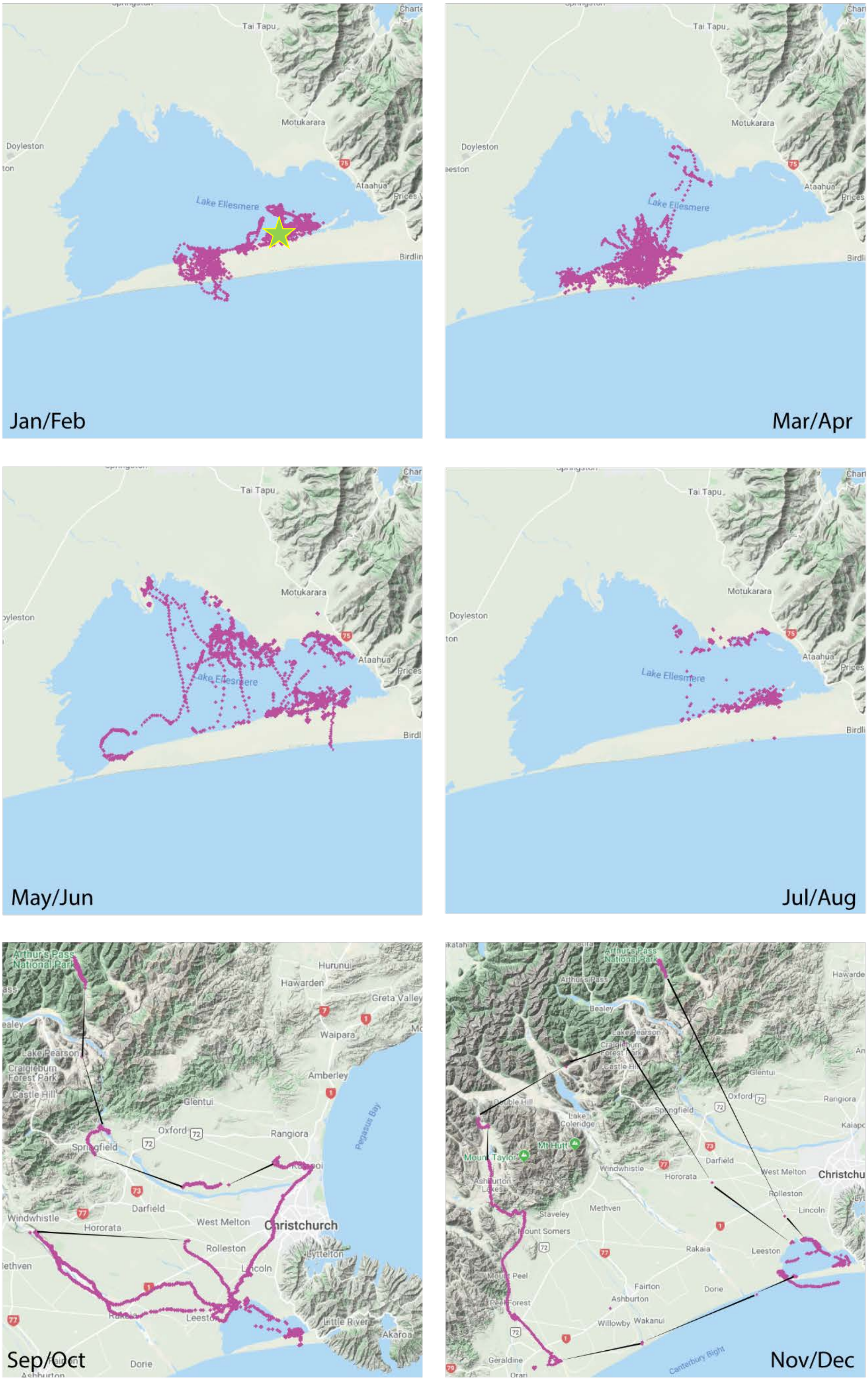

Figure 4.7. Illustration showing seasonal variation in the movements of bird 3519 "Charlie" from January 2019 to December 2019 at Lake Ellesmere/Te Waihora. Green star indicates site where individual was fitted with device. Black lines indicate trajectory of bird when flying between locational fixes.

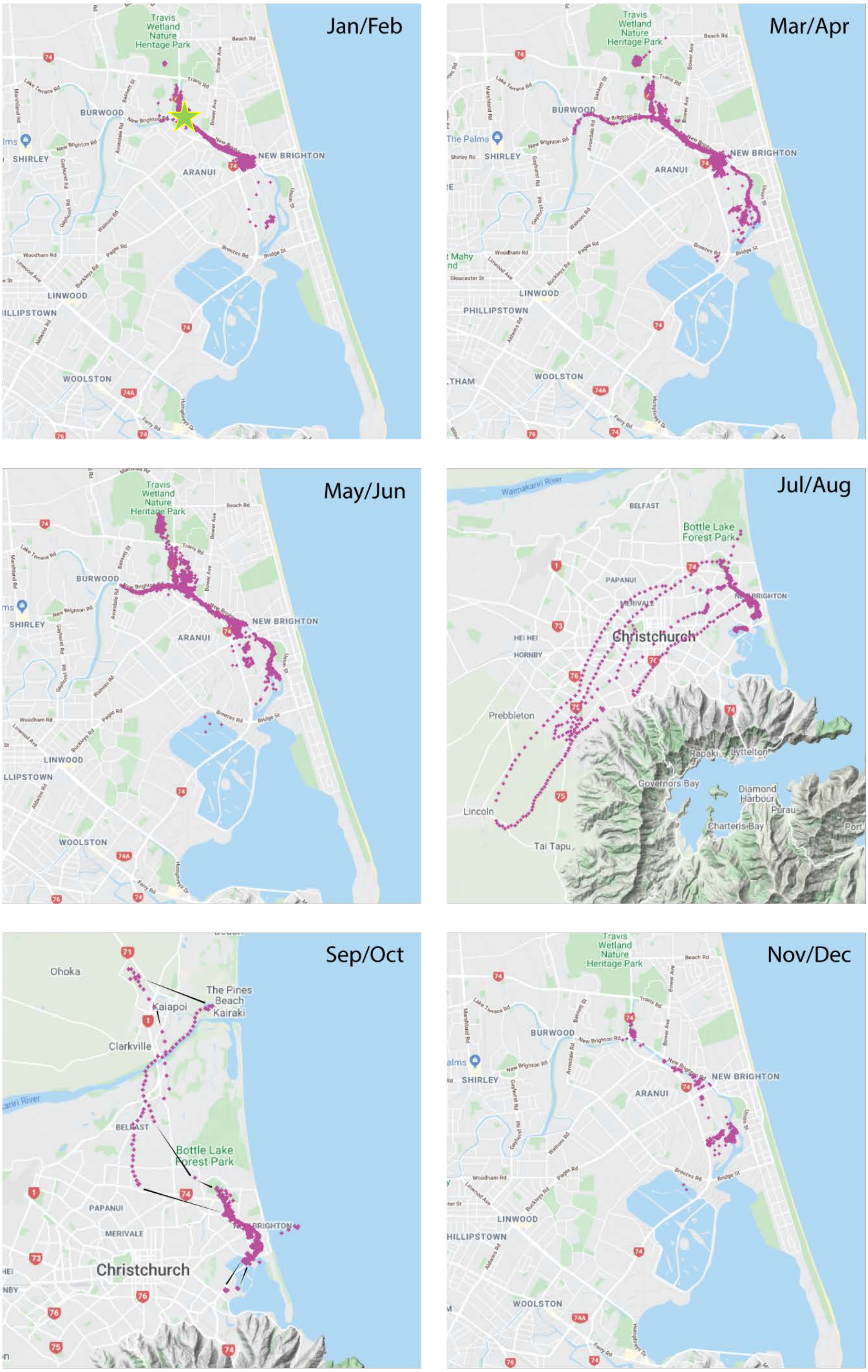

Figure 4.8. Illustration showing seasonal variation in the movements of bird 3594 “Maverick” from January 2019 to December 2019 in Christchurch city. Green star indicates site where individual was fitted with device. Black lines indicate trajectory of bird when flying between locational fixes.

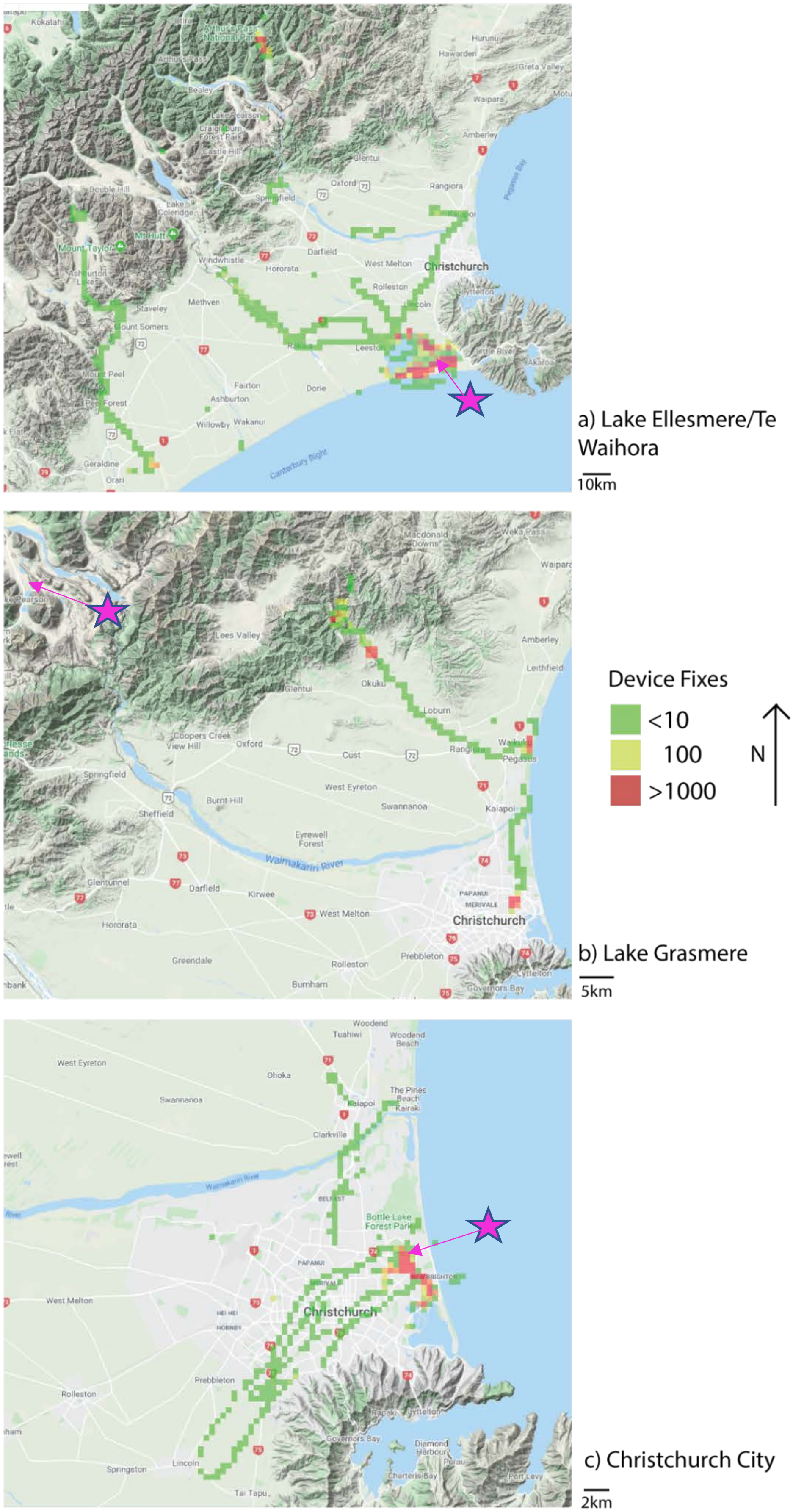

Figure 4.9. Illustration showing location densities for all tagged birds; a) n = 3, b) n = 1, c) n = 4, from January 2019 to December 2019. Pink stars indicate sites where individuals were fitted with devices.

4.4 Discussion

Only three of the ten tagged individuals were communicating by December 2019 after being fitted in January 2019 (Table 4.1). Two birds from Lake Ellesmere/Te Waihora failed after three months, one bird from Christchurch failed after six months and another two birds after ten months (Table 4.1). Only a single Lake Grasmere bird made it to the coast in September and has since continued to transmit data. Telemetry data collected suggest that Lake Ellesmere/Te Waihora and Lake Grasmere geese are more likely to perform longer, faster and higher flights than those from Christchurch city. The latter flew shorter distances in total (Figure 4.2) had smaller home ranges throughout the whole year (Figure 4.1) and exhibited the densest patches of locational fixes (Figure 4.9 c)).

Dispersal of birds 3519 and 3509 to the Southern Alps in spring reflects the findings from White (1986) that suggested many geese moved away from colonial breeding to isolated occurrences in valleys and lakes in the mountains. Similarly, the movements of Canada geese in Christchurch reflect findings that residency behaviours are becoming more prevalent (Groepper et al. 2008; Dolbeer et al. 2014; Dorak et al. 2017; Crossland 2018, unpublished data). Average home range size of city birds was 906 ha (9.06 km^2) from all recordings, this is smaller than findings by Groepper et al. (2008) in Lincoln Nebraska (pop. 284,736) which found a residency population of ~4000 geese with an average of 2500 ha (25 km^2), however Groepper et al. (2008) used non-GPS neck collars, thus accuracy was limited to visual observations. Population results showed there were many overwintering geese in Christchurch (see Chapter 3). Thus, suggesting an influx of geese from outside of the city to forage on red zone habitats that provided a proximate high yield sustenance throughout the winter. In the USA cities can act as sanctuaries that protect waterfowl from hunting pressures in winter, acting as a selective pressure assisting a possible shift to residency behaviours (Balkcom 2010; Pilotte et al. 2014; Dorak et al, 2017). Velocity and altitude data from tagged geese in winter (Figure 4.4) suggest that there were consistent low altitude and low speed flights that coincided with the foraging observations seen in Christchurch (see Chapter 3). Further, the relationship between altitude and velocity in Figure 4.6 show very few high-altitude flights in autumn and winter compared to spring and summer.

The major increases in mean velocity and altitude in spring (Figure 4.4) resulted from exploratory flights by birds 3519 and 3594 (Figure 4.7; Figure 4.8) and also by bird 3509 that resided on the coast in September and returned to the alps in the same month for the breeding season. Despite a handful of long-distance flights there was a long period of time with little movement while geese nested. Bird 3519 was isolated to a valley in the Southern Alps (Figure 4.7, inset image 5 & 6), bird 3594 returned to the vicinity of the Avon/ Ōtākaro River and bird 3509 settled in a valley on the Okuku River (Figure 4.9). The period of increased activity in spring is brief but also fairly unpredictable as geese appear to be undecided as to where they are headed to breed. This was very clear with goose 3519 that flew to the west along the Rakaia River and back to Lake Ellesmere/Te Waihora several times and then ultimately flying north and along the Waimakariri River into the Alps (Figure 4.7). It was observed and predicted that geese utilise these major river corridors to navigate into the Southern Alps (White 1986; Marchant & Higgins 1990); Holloway et al. (1987) found that banded geese had migrated to the upper Waimakariri River catchments from Lake Ellesmere/Te Waihora. Pre-moult, bird 3519 had returned to Lake Ellesmere/Te Waihora but before moulting it took another long-distance flight south and then inland to the Alps again (Figure 4.7, inset image 6). This reinforces a concern about unpredictability in Canada goose flight behaviours.

Bird 3519 flew parallel to the SW-NE airport runway <1km away at a height between 100 and 200 m ASL, a speed 10 to 18 m/s and from 18:37 to 18:47 pm on September 28th, 2019. The flight started at 17:40 pm from the north end of Lake Ellesmere/Te Waihora passed through Kaiapoi at 19:10 pm and ended 19:31 pm at Whites Road Recreation Reserve, Ohoka. There were no other recorded flights in this vicinity or at this height throughout the year. Bird 3519 took a different return flight from the Alps in December. Though only a single tagged bird was recorded performing these flights we could speculate that it is not the only goose to use these flight paths.

Kaiapoi appears to be a key "halfway-hotel" for geese travelling to and from the Southern Alps. Birds 3509, 3519 and 3594 all visited the same water bodies between Kaiapoi and Waikuku/Pegasus before flying inland, returning from the alps or flying back to the city (Figure 4.7; Figure 4.8; Figure 4.9).

Most clear of all out of all data collected was a trend in daily flight behaviours. There were two periods of increased flight activity represented by altitude and velocity sharing similar patterns (Figure 4.5). First rising at 05:00 until 09:00 am followed by a short bump at 11:00 am and then a final rise between 16:00 and 20:00 pm (Figure 4.5). Geese in the city were often found foraging in the red zone during the middle of the day (10:00 am to 14:00 pm) with a significant drop in foraging after 14:00 pm (see Chapter 3), suggesting there is a shift to other behaviour types which may coincide with the decrease in mean altitude and velocity seen in Figure 4.5. Geese at Lake Ellesmere/Te Waihora take advantage of agricultural pasture around the lake, particularly on the northern and southern shores and the city birds take advantage of the red zone paddocks.

4.5 Conclusions

Outside of spring, there were few if any flights travelling to the west of the city within range of the International Airport that would cause concern (Figure 4.7; Figure 4.8; Figure 4.9 b)). Nevertheless, dense populations of Canada geese within an urban environment still pose threats to humans that range from water contamination (Allan et al. 1995) including disease transmission vectors (Kullas et al. 2002) and collisions with aircraft (Allan 2002, Dolbeer et al. 2014). Airstrikes involving Canada geese have resulted in deaths in the USA, 24 died in the destruction of a $190US million U.S.A.F. craft (Dolbeer et al. 2000). Resulted in civil emergencies such as U.S. Airways flight 1549 that ditched into the Hudson River with 155 unharmed people onboard after striking several Canada geese (Marra et al. 2009). Hence, large populations of geese in urban habitats that have little reason to leave pose risks to humans across several vectors.

It is acknowledged that this investigation began with a limited number of tracking devices and lost communication with half of the birds within six months of manipulation (Table 4.1). Though devices provide great detail of Canada goose movements and spatial trends, the lack of sample size may only provide a glimpse into the overall situation of population dynamics within the region. This investigation has achieved its aims in identifying and confirming past predictions of Canada goose movement strategies along river corridors between the Southern Alps and the coast. It has also identified key periods of diurnal and seasonal variation in goose flights and when they may most likely present the greatest concern to civil aviation and the Christchurch International Airport properties. An increase in device sample size across more lake habitats including those in the west of the city may provide a better resolution of how the east and west populations interact. Because there are fluctuations between 1000 and 4000 geese in Christchurch (Crossland 2018, unpublished data) it is important to continue tracking individuals to identify any interactions with non-resident populations in the long-term.

CHAPTER 5

GENERAL CONCLUSIONS

5.0 Thesis conclusions

Following nearly a century since the introduction of 50 individuals, the Canada goose has exhibited continual population growth despite numerous invasive management strategies. Responsibilities had become localised as the national gamebird authorities (Fish & Game) transferred the goose from a game to pest species, removing it from their national portfolio. Thus, regional councils and private organisations have had to develop their own methods for surveillance and control. This is not an easy task, as prior to this study, the behaviours and movements exhibited by geese had not been directly measured or explored with GPS technologies in Christchurch. The findings in this study have revealed several patterns of movement, behaviour and population across diurnal and seasonal scales in an urban environment and its surrounding rural landscapes. Further, this study has identified when patterns of goose movements are most likely to pose greater risk to civil and military aviation in this region of New Zealand. Together, this information should help facilitate the monitoring and control of Canada goose populations that pose a hazard to human activity and welfare.

The use of GPS/GSM collars provided great detail of the movements, behaviour and spatial patterns of Canada geese. Though a small sample size, that became smaller due to malfunctions and death of individuals, this study was able to confirm that there was no concerning bias in telemetry data between GPS-tagged and non-GPS-tagged geese. Two GPS-tagged birds were also believed to have successfully reproduced during this investigation (the reproductive status of the other birds could not be determined). The density of location fixes in a location with numerous nests suggested that it had nested. However, both birds had stopped transmitting during the same period. One of these birds was relocated in January 2020 and the device appeared to be damaged. Another bird with coloured leg-bands had also successfully bred at The Groynes recreational park. These observations provide confidence that the foreign objects, such as collars and bands, may not necessarily be affecting reproductive abilities. Nevertheless, an increase in sample size would improve the resolution of any minor effect of tag that may be present. Importantly, this study has found that this type of tracking device is suited to the Canada goose and possibly other similarly sized waterfowl. Increasing the scope of this type of passive management would improve the accuracy and efficiency of approaches to population control.

Canada goose movements were most likely to be faster, longer and higher in August and September, the edge of winter and spring, as geese dispersed for the breeding season. Movements were also more likely to occur between 05:00 to 09:00 am and from 16:00 to 20:00 pm that indicated trips between roosting and foraging sites. Foraging was the most common behaviour observed for all habitats, particularly the red zone paddocks in Christchurch. There was a significant increase in foraging during Autumn as geese focused on improving body condition for winter (White 1986). Win (2002) also found that goose foraging was more frequent in this period at Lake Grasmere. Low altitude and slow flights appeared to be consistent through autumn and winter highlighting that geese are still mobile in this time, contrary to populations that overwinter in Chicago urban environments that conserved much of their energy rather than venture to forage on suburban and agricultural sites (Dorak et al. 2017).

Density of geese increased during winter in the city as did the presence of geese on red zone paddocks, suggesting either an influx of geese from external populations or a consolidation of urban residents to these optimal sites. Approximately 582 geese overwintered at Lake Grasmere in 2019. This is considerably higher than the ~150 recorded in 1999 and higher than the peak of 430 in autumn at Lake Grasmere (Win 2002), indicating that there are more geese frequenting the alpine lakes and more overwintering there. Thus, alpine populations may not descend to the coast to overwinter as much as previously predicted. As the red zone paddocks provide year-round grass yields for urban geese, the agricultural improvements to grasses on high-country farms may be providing a similar effect on goose residencies at Lake Grasmere.

Movement patterns by a couple of the GPS-tagged geese confirmed previous studies that predicted their use of wide river corridors for navigation (White 1986; Marchant & Higgins 1990) and supported findings by Holloway et al. (1987) that had first observed it. Observing the use of the river corridors into the mountains by geese provides more confidence in when and where to focus attentions for management plans. The use of water bodies in the Kaiapoi and Pegasus townships as a pre- and post-flight roosting place also provide avenues for targeting the long-distance migratory groups that may pose the greatest risk to aviation in the region.

Canada goose behaviour varied most due to habitat type rather than diurnal and seasonal variation. Sedentary behaviours were most common on urban lakes and foraging was significantly more common on red zone paddocks and similar between river and lake sites. Preening was most frequent during summer and on lakes, coinciding with the annual moult. During the moulting period (~34 days long) there were significant increases in the density and presence of geese at Styx Mill Reserve and on the Avon/Ōtākaro River Corridor, particularly near the Wainoni Rowing Club. The bird from Lake Grasmere moulted at the river site having been tagged during the previous moult in the Southern Alps. This indicates that there are variations in moult-site fidelity for Canada geese and also that birds from the Alps will descend to the coastal lakes to moult.

Much of the previous management of the Canada goose has revolved around the damage and competition they inflict to farmland and the domesticated animals reared. Culls have often been a practice for population control and have resulted in geese adapting to this pressure. The decrease of breeding colonies in the 1980's had resulted in fragmented and isolated breeding grounds (Holloway et al. 1987) that make it more difficult to predict patterns of movement. It also presents a more arduous task to identify the population interactions between large and small breeding groups. This study has shown that at least two geese were part of these isolated groups breeding in the mountains. The implementation of GPS collars in larger numbers could help alleviate the difficulty in locating more of these congregations and also how they move between fragmented hot spots and the larger colonies.

The information presented in this study provides confirmation that the GPS collars provide unprecedented detail into the movements and locational fixes of Canada geese in Canterbury and Christchurch city. It also highlights some of the difficulties encountered by tracking technologies and the vulnerabilities of small sample sizes. This preliminary investigation into the movements, positioning, and behaviours of Canada geese acts as a first step into improving our understanding of urban, suburban and rural population dynamics that should assist the future management strategies of this pest species in New Zealand.

5.1 Future research

My call to increase sampling of tracked geese is currently underway. Recent work to increase the number of GPS collars on Canada geese in Christchurch city took place during the January 2020 moult period, with another 5 devices fitted to geese from three different locations; 2 at Styx Mill Reserve, 2 at Lake Kate Sheppard and 1 at The Groynes. Three of these new devices have been fitted to geese on urban lakes in the west of Christchurch to improve the understanding of how they interact with the eastern habitats and also how they may present risk closer to the airport. Responsibilities for future monitoring of all devices will be shared among staff and volunteers from The Christchurch International Airport and The University of Canterbury.

Considerations for the next moult period should include the installation of more devices at other locations in Canterbury. Following another year of data collection from a larger sample size, more accurate determinations may be made about where to target another group of geese for tracking. As Canada geese populations continue to grow (and are no longer managed on a national scale) alongside the growth of air travel, collecting information on their movements into the future will be important in the mitigation of risks to civil and military aviation in New Zealand.

REFERENCES

Abraham, K. F., Jefferies, R. L. & Alisauskas, R. T. (2005). The dynamics of landscape change and snow geese in mid-continent North America. *Global Change Biology*, 11: 841–855.

Allan JR. (2006). International best practice standards for aerodrome bird control. Recommended Practices No. 1. International conference, St. Louis, MO; 21–24 August 2006; St. Louis, MO: Birdstrike committee USA/Canada Meeting.

Allan, J. R. (2002). The costs of bird strikes and bird strike prevention. Pages 147–155 in L. Clark, editor. Proceedings of the National Wildlife Research Centre symposium, human conflicts with wildlife: economic considerations. U.S. Department of Agriculture, National Wildlife Research Centre, Fort Collins, Colorado, USA.

Allan, J. R., Kirby, J. S. & Feare, C. J. (1995). The biology of Canada geese Branta canadensis in relation to the management of feral populations. *Wildlife Biology*, 1(1): 129-143. https://doi.org/10.2981/wlb.1995.018

Altman, J. (1974). Observational Study of Behaviour: Sampling Methods. *Behaviour*, 49(3/4): 227-267.

Anderson, M. G. & Padding, P. I. (2015). The North American approach to waterfowl management: synergy of hunting and habitat conservation. *International Journal of Environmental Studies*, 72: 810-829. https://doi.org/10.1080/00207233.2015.1019296

Arrington, D.P. (1994). U.S. air force bird aircraft strike hazard (BASH) summary report for 1989-1993. *Bird Strike Committee Europe*, 22: 201-208.

Austin, G. E., Rehfisch, M. M., Allan, J. R. & Holloway, S. J. (2010). Population size and differential population growth of introduced Greater Canada Geese *Branta canadensis* and re-established Greylag Geese *Anser anser* across habitats in Great Britain in the year 2000. *Bird Study*, 54(3): 343-352.

Baker, A. J. (1998). Identification of Canada Goose stocks using restriction analysis of mitochondrial DNA. Pages 435-443 in Biology and Management of Canada Geese (D. H. Rusch, M. D. Samuel, D. D. Humburg, and B. D. Sullivan, Eds.). Proceedings of the International Canada Goose Symposium, Milwaukee, Wisconsin.

Balkcom, G. D. (2010). Demographic parameters of rural and urban resident Canada Geese in Georgia. *Journal of Wildlife Management*, 74: 120–123.

Balmer, D.E., Gillings, S., Caffrey, B. J., Swann, R. L., Downie, I. S. & Fuller, R. J. (2013). *Bird atlas 2007-2011: The breeding and wintering birds of Britain and Ireland*. Thetford: BTO Books.

Barron, D. G., Brawn, J. D. and Weatherhead, P. J. (2010). Meta-analysis of transmitter effects on avian behaviour and ecology. *Methods in Ecology and Evolution*, 1: 180-187. Batsford Ltd. Fakenham Press Ltd., Norfold.

Baxter, A. T. & Robinson, A. P. (2007). Monitoring and influencing feral Canada goose (*Branta canadensis*) behaviour to reduce birdstrike risks to aircraft. *International Journal of Pest Management*, 53(4): 341-346.

Bellrose, F. C. (1980). Ducks, Geese and Swans of North America. Stackpole, Harrisburg, PA. Bird Strike Committee meeting (Volume 1), http://www.int-birdstrike.org/Warsaw_Papers/

Bird, J. (1996). Birds: crash puts new focus on old problem. *Air Force Times*, 26: 10-15.

Blackwell, B. F. & Wright, S. E. (2006). Collisions of Red-tailed Hawks (*Buteo jamaicensis*), Turkey Vultures (*Cathartes aura*), and Black Vultures (*Coragyps atratus*) with Aircraft: Implications for Bird Strike Reduction. *USDA National Wildlife Research Center* - Staff Publications. 410. https://digitalcommons.unl.edu/icwdm_usdanwrc/410

Blurton-Jones, N.G. (1956) Census of breeding Canada Geese, 1953. *Bird Study*, 3: 153-170 .

Bodey, T. W., Cleasby, I. R., Bell, F., Parr, N., Schultz, A., Votier, S. C. and Bearhop, S. (2018). A phylogenetically controlled meta-analysis of biologging device effects on birds: Deleterious effects and a call for more standardized reporting of study data. *Methods in Ecology and Evolution*, 9(4): 946-955.

Both, C., Bouwhuis, S., Lessells, C. M. & Visser, M. E. (2006). Climate change and population declines in a long-distance migratory bird. *Nature*, 441(4): 81-83. doi:10.1038/nature04539.

Bowlin, M. S., Henningsson, P., Muijres, F. T., Vleugels, R. H. E., Liechti, F. and Hedenström, A. (2010). The effects of geolocator drag and weight on the flight ranges of small migrants. *Methods in Ecology and Evolution*, 1: 398-402.

Bradbeer, D. R., C. Rosenquist, T. K. Christensen, and A. D. Fox. (2017). Crowded skies: Conflicts between expanding goose populations and aviation safety. *Ambio*, 46(2): 290-300. doi:10.1007/s13280-017-0901-2.

Bradbeer, D.R., Rosenquist, C., Christensen, T.K. & Fox, A.D. (2017). Crowded skies: conflicts between expanding goose populations and aviation safety. *Ambio* 46(Suppl. 2): S290-S300.

Buchsbaum, R. N., Wilson, J. & Valiela, I. 1986. Digestibility of plant constituents by Canada geese and Atlantic brant. *Ecology* 67 (2): 386-393.

Buij, R., Melman, T. C. P., Loonen, M. J. J. E., and Fox, A. D. (2017). Balancing ecosystem function, services and disservices resulting from expanding goose populations. *Ambio*, 46(Suppl. 2): 301-318. DOI: 10.1007/s13280-017-0902-1.

Calenge, C. (2006) The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. *Ecological Modelling*, 197: 516-519.

Casper, R.M. (2009) Guidelines for the instrumentation of wild birds and mammals. *Animal Behaviour*, 78: 1477–1483.

Civil Aviation Authority (2002). CAP 680 Aerodrome bird control. [CAA publication]. Civil Aviation Authority, London

Clausen, K. K. and Madsen, J. (2014). Effects of neckbands on body condition of migratory geese. *Journal of Ornithology*, 155: 951-958.

Conover, M. R. & Kania, G. S. (1991). Characteristics of feeding sites used by urban-suburban flocks of Canada geese in Connecticut. *Wildlife Society Bulletin*, 19(1): 36-38. https://www.jstor.org/stable/3782413?seq=1#page_scan_tab_contents

Conover, M. R., and G. G. Chasko (1985). Nuisance Canada Goose problems in the eastern United States. *Wildlife Society Bulletin* 13: 228–233.

Cooleman S., Anselin A., Beck O., Kuijken E. & Lens L. (2005). Movements and mortality of Canada Goose *Branta canadensis* in Flanders. *Natuur oriolus* 71:152-160.

Crossland, A.C. (2013). Wetland bird monitoring at the Avon-Heathcote Estuary and Bromley Oxidation ponds, Christchurch: August 2009 to July 2010. *Notornis* 60: 151-157.

Crossland, A.C., Crutchley, P., Alexander, B., Harrison, K., Petch, S. & Walker, J. (2015). A three-year census of wetland birds on Lake Ellesmere/Te Waihora, Canterbury during the post-breeding period. *Notornis* 62: 121-129.

del Hoya, J., Elliot, A, Sargatal, J. (1992). *Handbook of Birds of the World*. Lynx Edicions, Barcelona.

Delany, S.N. (1992) Survey of introduced geese in Britain, summer 1991: provisional results. Report to JNCC, MAFF and National Trust. Wildfowl and Wetlands Trust , Slimbridge, 38 pp.

DeVault, T. L., Blackwell, B. F., Seamans, T. W. & Belant, J. L. (2016). Identification of Off Airport Interspecific Avian Hazards to Aircraft. *The Journal of Wildlife Management*, 80(4): 746-752. DOI: 10.1002/jwmg.1041.

DeVault, T. L., Blackwell, B. F., Seamans, T. W., Begier, M. J., Kougherm J. D., Washburn. J. E., Miller, P. R. & Dolbeer, R. A. (2018). Estimating Interspecific Economic Risk of Bird Strikes With Aircraft. Wildlife Society Bulletin, 42(1): 94-101. DOI: 10.1002/wsb.859

Dolbeer, .A. (2006). Height distribution of birds as recorded by collisions with civil aircraft. *Journal of Wildlife Management*, 70(5): 1345-1350.

Dolbeer, R. A., and P. Eschenfelder. (2003). Amplified bird-strike risks related to population increases

Dolbeer, R. A., S. E. Wright, and E. C. Cleary. (2000). Ranking the hazard level of wildlife species to aviation. *Wildlife Society Bulletin*, 28: 372–378.

Dolbeer, R. A., S. E. Wright, J. Weller, and M. J. Begier. (2014). Wildlife strikes to civil aircraft in the United States 1990-2013. U.S. Department of Transportation, Federal Aviation Administration, Office of Airport Safety and Standards, Serial Report 20, Washington, D.C., USA.

Dolbeer, R. A., Seubert, J. L. & Begier, M. J. (2014). Population trends of resident and migratory Canada geese in relation to strikes with civil aircraft. *Human-Wildlife Interactions*, 8 (1): 88-99.

Dorak, B. E., Ward, M. P., Eichholz, M. W., Washburn, B. E., Lyons, T. P. and Hagy, H. M. (2017). Survival and habitat selection of Canada Geese during autumn and winter in metropolitan Chicago, USA. *Ornithological Applications*, 119: 787-799. DOI: 10.1650/CONDOR-16-234.1

Dunn, O. J. (1964). Multiple comparisons using rank sums. *Technometrics*, 6: 241-252.

Durant, J. M., Hjermann, D. O., Ottersen, G. and Stenseth, N. C. (2007). Climate and the match or mismatch between predator requirements and resource availability. *Climate Research*, 33: 271-283.

Enstipp, M. R., Frost J., Hollmen, T. E., Andrews, R. D. and Frost, C. (2015). Two methods of radio transmitter attachment and their effects on the behavior and energetics of captive long-tailed ducks (*Clangula hyemalis*) during winter. *Animal Biotelemetry*, 3: 36. doi.org/10.1186/s40317-015-0082-3

Eschenfelder P. 2000. Jet engine certification standards. International conference held in Amsterdam, 17–20 April 2000, Amsterdam, Netherlands, International Bird Strike Committee 25:535–540.

Fairaizl, S. D. (1992) An integrated approach to the management of urban Ca nada Goose depredations. In: Borrecco, J.E. & Marsh, R.E (eds.). Proceedings of the 15th vertebrate pest conference University of California, Davis Ca: 105-109.

Fish & Game New Zealand. (2011). Canada Geese – hunting status. *Fish & Game New Zealand,* *https://fishandgame.org.nz/assets/Uploads/Canada-Geese-status.pdf*; Accessed on December 16th, 2019.

Flight Safety Foundation. (2002). Flight Safety Foundation approach-and-landing accident reduction briefing note 4.2-energy management. *Flight Safety Digest*. August-November: 75-80.

Fox, A. D. & Abraham, K. F. (2017). Why geese benefit from the transition from natural vegetation to agriculture. *Ambio*, 46 (Suppl. 2): S188-S197.

Fox, A. D. & Madsen, J. (2017). Threatened species to super-abundance: The unexpected international implications of successful goose conservation. *Ambio*, 46: 179-187. DOI 10.1007/s13280-016-0878-2

Gates, R. J., D. F. Caithamer, W. E. Moritz, and T. C. Tacha (2001). Bioenergetics and nutrition of Mississippi Valley population Canada Geese during winter and migration. *Wildlife Monographs*, 146: 1–65.

Gauthier, G. (1998). Population model of the greater snow goose: projected impacts of reduction in survival on population growth rate. Pages 65-80 *in* B. D. J. Batt, editor. The greater snow goose: report of the Arctic goose habitat working group. Arctic Goose Joint Venture

Special Publication. U.S. Fish and Wildlife Service, Washington, D.C., USA, and Canadian Wildlife Service, Ottawa, Ontario, Canada.

Geen, G. R., Robinson, R. A. and Baillie, S. R. (2019). Effects of tracking devices on individual birds – a review of the evidence. *Journal of Avian Biology*, e01823. Doi: 10.1111/jav.01823

Gessaman, J. A. and Nagy, K. A. (1988). Transmitter loads affect the flight speed and metabolism of homing pigeons. *Condor*, 90(3): 622–668.

Gibbons, D.W., Reid, J.B. & Chapman, R.A. (1993). The New Atlas of Breeding Birds in Britain and Ireland: 1988–1991. T. & A.D. Poyser, London

Groepper, S. R., P. J. Gabig, M. P. Vrtiska, J. M. Gilsdorf, S. E. Hygnstrom, and L. A. Powell (2008). Population and spatial dynamics of resident Canada Geese in southeastern Nebraska. *Human–Wildlife Conflicts*, 2: 270–276.

Hansard (2005). Parliamentary Questions, 14 June 2005: Column 241W.

Heather, B. D. & Robertson, H. A. (1996). The field guide to the birds of New Zealand. Auckland, New Zealand, Penguin Books. 432 p.

Hill, M. R. J., and R. B. Frederick. (1997). Winter movements and habitat use by Greater Snow Geese. Journal of Wildlife Management 61: 1213-1221. http://dx.doi.org/10.2307/3802119

Holloway, J. D. R., Scott, R. R. & Wilson, K-J. (1987). Management of the Canada goose in the South Island of New Zealand. Unpublished Lincoln University Report, Lincoln, Canterbury. 14 pp.

Imber, M. J. (1971a). The identity of New Zealand's Canada geese. *Notornis,* 18: 253–261.

Imber, M.J. (1971). Canada geese studies in Canterbury. *Ammohouse Bulletin,* 1(30).

Imber, M. J. & Williams, G. R. (1968). Mortality Rates of a Canada Goose Population in New Zealand. *The Journal of Wildlife Management*, 32(2): 256-267. URL: http://www.jstor.org/stable/3798969

Kölzsch, A., Neefjes, M., Barkway, J., Müskens G. J. D. M., et al. (2016). Neckband or backpack? Differences in tag design and their effects on GPS/accelerometer tracking results in large waterbirds. *Animal Biotelemetry*, 4: 1-14. Doi: 10.1186/s40317-016-0104-9

Kullas, H., M. Coles, J. Rhyan, and L. Clark (2002). Prevalence of Escherichia coli serogroups and human virulense factors in faeces of urban Canada Geese (Branta canadensis). *International Journal of Environmental Health Research*, 12: 153–162.

Lamb, R. C. (1964). Birds, beasts, & fishes. The first hundred years of the North Canterbury Acclimatisation Society. Christchurch, New Zealand, *North Canterbury Acclimatisation Society*. 184 p.

Lenth, R. V. (2016). Least-Squares Means: The R Package lsmeans. *Journal of Statistical Software*, 69(1): 1-33.DOI:10.18637/jss.v069.i01

Maccarone, A. D. & Cope, C. H. (2004). Recent trends in the winter population of Canada geese (*Branta canadensis*) in Wichita, Kansas. *Transactions of the Kansas Academy of Science (1903-)*, 107(1/2): 77-82.

Maloney, R.F. (1999). Bird populations in nine braided rivers of the Upper Waitaki Basin, South Island, New Zealand: changes after 30 years. *Notornis* 46: 243-256.

Marchant, S. & Higgins, P. J. (eds). (1990). Handbook of Australian, New Zealand, and Antarctic birds. Vol.1. Ratites to ducks. Melbourne, Oxford University Press.

Marra, P. P., Dove C. J., Dolbeer, R., Dahlan, N. F., Heacker, M., Whatton, J. F., Diggs, N. E., France, C. and Henkes, G. A. (2009). Migratory Canada Geese cause crash of US Airways Flight 1549. *Frontiers in Ecology and the Environment*, 7: 297–301.

McIntyre, T. (2015). Animal telemetry: Tagging effects. *SCIENCE*, 349(6248): 567-568.

McWilliams, S. R. and Raveling, D. G. (1998). Habitat use and foraging behaviour of cackling Canada and Ross geese during spring: implications for the analysis of ecological determinants of goose social behaviour. pp 167-178 in Rusch, D.H., Samuel, M.D., and Sullivan, B.D., (eds.). Biology and Management of Canada Geese, Proceedings of the International Canada goose symposium.

Milsom, T. P. (1990) The use of bird strike statistics to monitor the hazard and evaluate risk on UK civil aerodromes. Proceedings of the 20th Bird strike Committee Europe, Helsinki: 303-320.

Mowbray, T. B., Ely, S. R., Sedinger, J. S. & Trost, R. E. (2002). Canada Goose (*Branta canadensis*). *In* The Birds of North America, No. 682 (A. Poole and F. Gill, eds.). The Birds of North America, Inc., Philadelphia, PA.

Ogilvie, M.A. (1969) The status of the Canada Goose in Britain 1967-1969. *Wildfowl,* 28: 79-85.

Ogilvie, M.A. (1977) The numbers of Canada Geese in Britain, 1976. *Wildfowl*, 28: 27-34.

Owen, M. (1980). *Wild Geese of the World: Their Life History and Ecology,* Batsford Ltd. Fakenham Press Ltd., Norfold.

Owen, M. (1983) The Aliens. *Wildfowl World*, 89: 16-19.

Owen, M. and Black, S.M. (1990) Tertiary level biology: waterfowl ecology. Blackie and Sons Ltd, London.

Parmesan, C. (2006). Ecological and Evolutionary Responses to Recent Climate Change. *Annual Review of Ecology, Evolution, and Systematics*, 37: 637-669.

Pe'er, G., Dicks, L. V., Visconti, P., Arlettaz, R., Ba´ldi, A., Benton, T. G., Collins, S., Dieterich, M. et al. (2014). EU agricultural reform fails on biodiversity. *Science*, 344: 1090-1092.

Pilotte, C., Reed, E. T., Rodrigue, J., and Giroux, J. F. (2014). Factors influencing survival of Canada Geese breeding in southern Quebec. *Journal of Wildlife Management*, 78: 231–239.

Potts, K. J. & Andrew, J. J. (1991) Canada geese feeding on farmland in North Canterbury high country. Wellington [N.Z.]: Head Office, Dept. of Conservation, c1991. 1 v. (Science & research series, 0113-3713; no. 39)

Raveling, D. G. (1979c). Traditional use of migration and winter roost sites by Canada Geese. *The Journal of Wildlife Management,* 43: 229-235.

Reif, J. (2013). Long-term trends in bird populations: A review of patterns and potential drivers in North America and Europe. *Acta Ornithologica*, 48: 1-16.

RStudio Team (2018). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA, URL http://www.rstudio.com/.

Schmutz, J. A. and Morse, J. A. (2000). Effects of neck collars and radio transmitters on survival and reproduction of emperor geese. *Journal of Wildlife Management*, 64(1): 231–237. doi:10.2307/3802995.

Sergio, F., Tavecchia, G., Tanferna, A., Jiménez, L. L., Blas, J., et al. (2015). No effect of satellite tagging on survival, recruitment, longevity, productivity and social dominance of a raptor, and the provisioning and condition of its offspring. *Journal of Applied Ecology*, 52: 1665-1675. Doi: 10.1111/1365-2664.12520

Shields, G. F. & Allan, C. (1987). Subspecies of the Canada Goose (Branta canadensis) Have Distinct Mitochondrial DNA's. *Evolution*, 41 (3): 662-666.

Shields, G. F., and Cotter, J. P. (1998). Phylogenies of North American geese: The mitochondrial DNA record. Pages 405-411 in Biology and Management of Canada Geese (D. H. Rusch, M. D. Samuel, D. D. Humburg, and B. D. Sullivan, Eds.). Proceedings of the International Canada Goose Symposium, Milwaukee, Wisconsin.

Spurr, E. B. and Coleman J. D. (2005). Review of Canada Goose Population Trends, Damage, and Control in New Zealand. *Landcare Research Science Series No. 30*: 1-32.

Stroud, D. A., Madsen, J. and Fox, A. D. (2017). Key actions towards the sustainable management of European geese. *Ambio*, 46 (Suppl. 2): S328-S338.

Tait, P., Vallance, S. & Rutherford, P. (2016). Expanding the conversational terrain: Using a choice experiment to assess community preferences for post-disaster redevelopment options. *Land Use Policy*, 55: 275-284. http://dx.doi.org/10.1016/j.landusepol.2016.04.013

Thaxter, C. B., Ross-Smith, V. H., Clark, J. A., Clark, N. A., Conway, G. J., Masden, E. A., Wade, H. M., Leat, E. H. K., Gear, S. C., Marsh, M., Booth, C., Furness, R. W., Votier, S. C. & Burton, N. H. K. (2016). Contrasting effects of GPS device and harness attachment on adult survival of Lesser Black-backed Gulls *Larus fuscus* and Great Skuas *Stercoraruis skua*. *Ibis*, 158: 279-290.

DeSisto, T. (2014). Summary of New York City Canada goose removals 2009 through 2013, USDA APHIS Wildlife Services, February 2014.

van der Jeugd, H.P., and Kwak, A. (2017). Management of a Dutch resident barnacle goose Branta leucopsis population: How can results from counts, ringing and hunting bag statistics be reconciled? *Ambio*, 46 (Suppl. 2): 251-261. DOI:10.1007/s13280-017-0900-3.

van Roomen, M. and Madsen, J. (eds.). (1992). Waterfowl and agriculture: Review and future perspective of the crop damage conflict in Europe. Slimbridge: IWRB. IWRB Special Publication No. 21.

Vandenabeele, S. P., Shepard, E. L. C., Grogan, A. & Wilson, R. P. (2012). When three percent may not be three per cent; device-equipped seabirds experience variable flight constraints. *Marine Biology*, 159: 1–14.

Vandenabeele, S. P., Grundy, E., Friswell, M. I., Grogan, A., Votier, S. C. & Wilson, R. P. (2014). Excess Baggage for Birds: Inappropriate Placement of Tags on Gannets Changes Flight Patterns. *PLoS ONE*, 9(3): e92657. doi:10.1371/journal.pone.0092657.

Vandenabeele, S. P., Shepard, E. L. C., Grémillet, D., Butler, P. J., Martin, G. R. & Wilson, R. P. (2015). Are bio-telemetric devices a drag? Effects of external tags on the diving behaviour of great cormorants. *Marine Ecology Progress Series*, 519: 239-249. doi:10.3354/meps11058

Weiser, E. L., Lanctot, R. B., Brown, S. C., Alves, J. A., Battley, P. F., Bentzen, R. *et al.* (2016). Effects of geolocators on hatching success, return rates, breeding movements, and change in body mass in 16 species of Arctic-breeding shorebirds, *Movement Ecology*, 4: 12 p. doi: 10.1186/s40462-016-0077-6.

White, E. G. (1986). Canada geese in New Zealand. Information Paper No. 4, Centre for Resource Management, Lincoln College, Lincoln, New Zealand. 40 p.

Wikelski, M., & Kays, R. (2020). Movebank: archive, analysis and sharing of animal movement data. Hosted by the Max Planck Institute for Animal Behaviour. www.movebank.org, (accessed on January 7th, 2020).

Williams, M. (1981). The duck shooter's bag. An understanding of New Zealand's wetland gamebirds. Wellington, New Zealand, Wetland Press. 123 p.

Wilson, R. P. & McMahon, C. R. (2006). Measuring devices on wild animals: What constitutes acceptable practice? *Frontiers of Ecology & Environment*, 4: 147–154.

Wilson, A. D. M., Wikelski, M., Wilson, R. P. & Cooke, S. J. (2015). Utility of biological sensor tags in animal conservation. *Conservation Biology*, 29(4): 1065-1075.

Win, A. (2001). Seasonal grazing of Canada goose (Branta canadensis) on high country farmland, Canterbury, New Zealand. MSc Thesis. Department of Pest Management and Conservation, Lincoln University, Lincoln, New Zealand. https://researcharchive.lincoln.ac.nz/handle/10182/2678

York, D. L., Cummings, J. L., Engeman, R. M. & Wedemeyer, K. L. (2000). Hazing and movements of Canada geese near Elmendorf Air Force Base in Anchorage, Alaska. *International Biodeterioration & Biodegradation,* 45: 103-110.